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Geology and Hydrology of the Neshannock Quadrangle, Mercer and Lawrence Counties, Pennsylvania

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Geology and Hydrology of the Neshannock Quadrangle, Mercer and Lawrence Counties, Pennsylvania

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Prepared by the United States Geological Survey,
Ground Water Branch, in cooperation with the
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GEOLOGY AND HYDROLOGY OF THE NESHANNOCK QUADRANGLE, MERCER AND LAWRENCE COUNTIES, PENNSYLVANIA

by
Louis D. Carswell and Gordon D. Bennett

ABSTRACT

The Neshannock 15-minute quadrangle is in northwestern Pennsylvania. It is separated into two nearly equal halves by the boundary line between Mercer and Lawrence Counties.

The quadrangle is entirely within the glaciated part of the Allegheny Plateau physiographic province. The surface consists of hilly upland between broad valleys of the Mahoning and Shenango Rivers and the Neshannock and Lackawannock Creeks. These streams are flowing upon thick glacial deposits in valleys which have a preglacial or interglacial origin. The flanks of the major valleys contain kames, kame terraces, and valley-train deposits. Most of the upland area is covered with glacial till.

The area is underlain by Mississippian and Pennsylvanian rocks, which dip to the south and southeast at approximately 15 feet per mile. Local structural highs are superimposed on the gently dipping strata by the draping of coal over thick sandstone, as a result of the differential compaction of sandstone and shale.

The Pennsylvanian and Mississippian rocks are composed mostly of alternating units of shale and sandstone. The Mississippian rocks are poorly exposed in the lower reaches of the tributaries entering the Mahoning and Shenango Rivers. The sandstones of the Pennsylvanian System do not extend continuously throughout the quadrangle but occur in poorly defined elongate belts. The sandstones intertongue laterally with shale. Locally they fill channels that cut completely through the shales, coalescing with sandstones lower in the section. In addition to sandstone and shale, the Pennsylvanian rocks contain thin beds of limestone, coal, and fireclay.

Ground water in the Neshannock quadrangle occurs in a complex flow system, through which precipitation infiltrates to the water table and is discharged into the streams draining the area. Some of the infiltrating water flows laterally, through the upper sandstones of the section, and discharges into the small upland streams; the remainder moves downward to the deeper sandstones and then flows laterally to the major streams of the region. The lower limit of the flow system is a direct fluid contact between the moving fresh water and the highly mineralized connate brine that saturates the deeper formations.

Wells in the upland areas of the Neshannock quadrangle obtain water predominantly from the sandstones of the section, but wells in the valleys may obtain water either from the sandstones or from unconsolidated Pleistocene sands and gravels. The individual sandstones may differ in permeability from one location to another, and the Pleistocene sands and gravels are generally discontinuous. Accurate prediction of well performance is, therefore, difficult. In general, wells in the upland areas will exhibit increases in specific capacity and decreases in static water level as they are extended into deeper sandstones. Wells in the major valleys will generally exhibit increases in specific capacity and slight increases in static level as they are deepened.

The chemical quality of the ground water is apparently controlled by a sequence of processes that occur as the water moves through the earth. Some evidence suggests that the quality of water obtained from a well in the upland areas may be improved by drilling into deeper sandstones, provided the well is not extended into rocks containing connate brine.

INTRODUCTION

Purpose and Scope

The sandstone aquifers of Pennsylvanian and Mississippian age constitute a large and largely undeveloped source of ground water in northwest Pennsylvania. Because of the variability in yields of wells penetrating these aquifers, and in anticipation of the future needs for ground water for domestic, municipal, and industrial uses in this area, an investigation of the geology and hydrology of the Neshannock quadrangle was made by the U. S. Geological Survey in cooperation with the Pennsylvania Geological Survey.

This report describes the areal distribution of lithologic units, the occurrence, quality, and movement of fresh water through these units, and the approximate contact between the fresh water and the salt water.

Location and Extent of the Area

The area discussed in this report includes the Neshannock 15-minute quadrangle, in northwest Pennsylvania. (See Fig. 1.) As thus defined, the area is bounded by lat. 41° N. and 41°15′ N. and long. 80°15′ W. and 80°30′ W. It includes 225 square miles in Lawrence and Mercer Counties, Pa.

Previous Investigations

Geological reconnaissance of the area was first carried on between 1836-1847 by the First Pennsylvania Geological Survey, results of which were published in the "Geology of Pennsylvania," by H. D. Rogers (1858). This survey recognized most of the beds of coal and limestone and, in general, the major stratigraphic and structural features of the area. Although time and increased knowledge brought the discovery of additional coal beds and changes in nomenclature and correlation of units, Roger's description of individual outcrops was good. His report provides a record of much of the early development of the mineral resources in the area.

I. C. White (1879 and 1880) contributed much to the understanding of the stratigraphy of Mercer and Lawrence Counties by his systematic descriptions and his correlations. Because of the scarcity of outcrops in the area, White's descriptions of the early mining and oil exploration

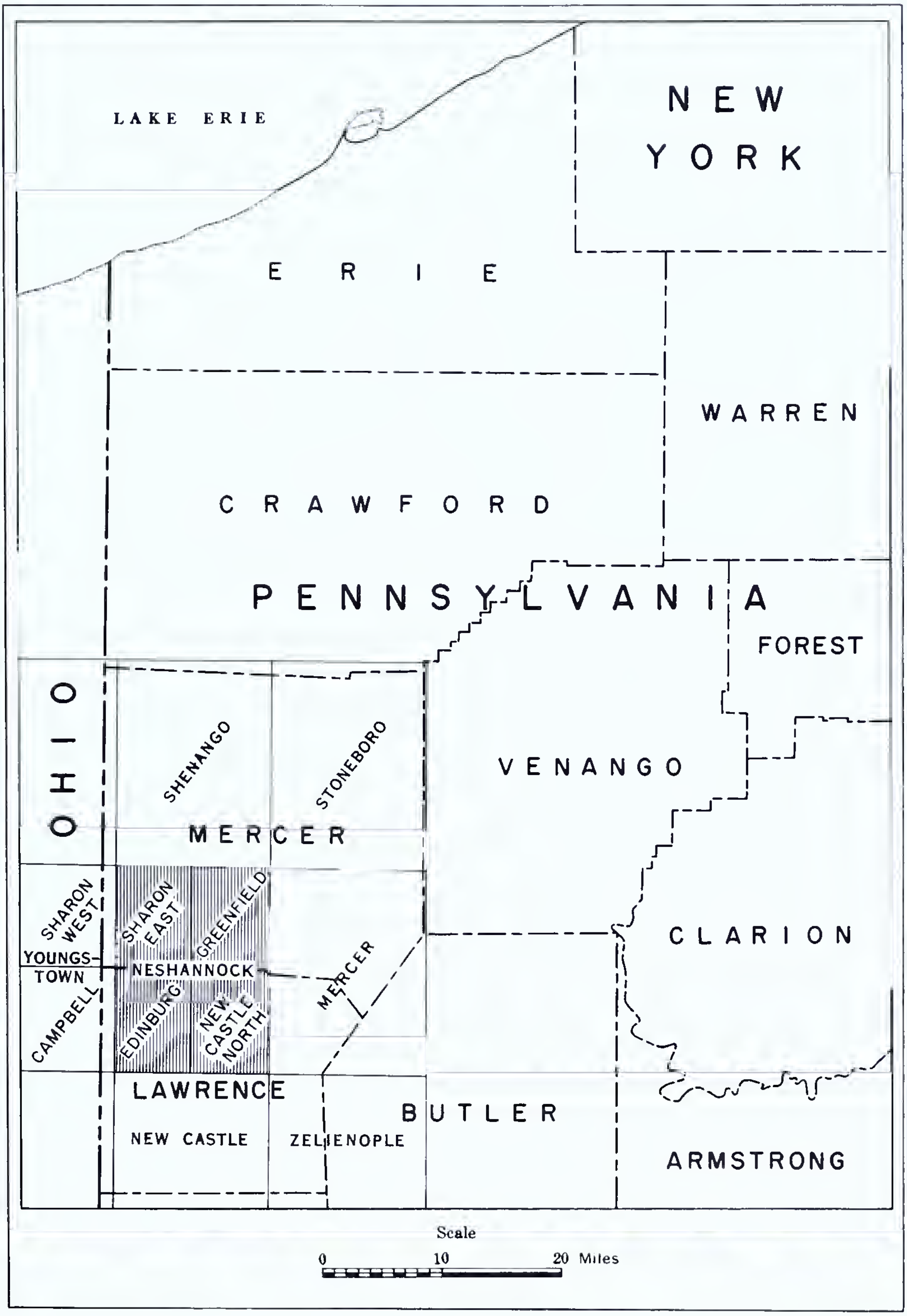

Figure 1. Index map of northwest Pennsylvania and northeast Ohio, showing area covered by this report and the adjacent counties and quadrangles.

are invaluable. He described the Pennsylvanian rocks by using mostly the terminology of the First Geological Survey (Rogers, 1858), with minor modifications and additions. His descriptions of the Mississippian rocks was a major contribution. The nomenclature he proposed for the units is still used, with only minor modifications that were made necessary by the development of rules for stratigraphic nomenclature. White's Lawrence and Mercer County reports are still the major references to the geology of the area.

Leggette (1936) made a reconnaissance of the ground-water resources of Lawrence and Mercer Counties as a part of a study of the ground-water resources of northwestern Pennsylvania. Leggette gathered information on domestic, industrial, and municipal ground-water supplies in the form of well logs, measurements of well depth, yield and drawdown, and the chemical quality of ground water. Geologic field work in the Neshannock quadrangle was concerned mainly with the study of the glacial deposits. Emphasis was placed on the origin of the buried valleys of northwestern Pennsylvania. Leggette's descriptions of local stratigraphy were taken from I. C. White (1879 and 1880), and from F. W. De Wolf (1929) who studied the New Castle quadrangle, immediately south of the Neshannock quadrangle.

Other reports on geologic investigations of adjacent areas are those of Richardson (1936) on the geology of the Butler and Zelienople quadrangles, southeast of the Neshannock quadrangle; and Cross, Shroeder, and Norris (1952) on the Water Resources of the Mahoning River Basin.

The report entitled "Geology of the Bedford Shale and the Berea Sandstone in the Appalachian Basin" (Pepper and others, 1954) contains many useful and informative stratigraphic correlations and descriptions of the Mississippian and Devonian rocks that are not exposed in the Neshannock quadrangle.

The mineralogy of the sandstone members of the Homewood and Connoquenessing Formations in the Mercer quadrangle and the southeast part of the Neshannock quadrangle was studied by T. E. Hendrix, who concluded (Hendrix 1957, p. 72) that the sandstones contained 60 to 98 percent quartz (including chert), 1 to 5 percent feldspar and muscovite, and less than 1 percent heavy minerals (principally leucoxene, subordinate tourmaline and zircon, and minor amounts of rutile, anatase, ilmenite, apatite, garnet, and chlorite); clay minerals and iron oxides make up the remainder of the composition. Hendrix noted that the quartz content of the Homewood was higher than that of the Connoquenessing. He noted also that the chert, feldspar, muscovite, and clay content of the Connoquenessing was higher than that of the Homewood. The zircon content of the Homewood was observed to be higher than its tourmaline content, whereas the reverse relationship existed in the Connoquenessing.

The geographic distribution, composition, and topographic form of the glacial deposits in the Neshannock quadrangle was described by Shepps and others (1959) in their study of the glacial deposits of northwest Pennsylvania.

METHODS USED IN THIS INVESTIGATION

Geologic maps of the New Castle North, Edinburg, Sharon East and Greenfield 7½-minute quadrangles (which make up the Neshannock 15-minute quadrangle) were prepared by using the scarce exposures of bedrock in the area and supplementing them with logs of wells obtained from water-well drillers. (See Plate 1.)

The thickness and sorting of glacial deposits were noted, where possible, to aid in identifying the different types of glacial deposits in the area. However, only the thickness of these deposits is shown on the maps accompanying this report.

During the course of this investigation, data (including more than 400 drillers logs) were collected for more than 700 wells in the Neshannock quadrangle. In addition, 17 wells were logged electrically, and a pumping test was made on well Mr-978, at West Middlesex, Pa. Locations of representative wells are shown in Plate 1 and descriptions of these wells appear in Table 2. Chemical analyses of water from 14 wells were made by the Quality of Water Branch, U. S. Geological Survey. The analyses are given in Table 3.

Field studies on which this report is based were started in 1952 by D. W. Greenman, who made a geologic reconnaissance and a well inventory as part of a proposed investigation of the ground-water resources of Lawrence County, Pa.

WELL-NUMBERING SYSTEM

The well-numbering system used in Pennsylvania includes a well-identification number and a well-location number. The identification number consists of a two-letter symbol for the name of the county in which the well is located followed by a serial number beginning with 1 in each county. The county symbols used in this report include Mr for Mercer County and La for Lawrence County. Thus, Mr-100 identifies the 100th well scheduled in Mercer County.

The well-location number is composed of two parts separated by a hyphen such as E2b-0804. The first part, E2b, refers to the coordinate system used in Pennsylvania to identify individual 7½-minute quadrangle maps. The coördinate system employs the use of the letters A through L (except I) along the west border of the State to designate from north to south each 15-minute interval of latitude. Similarly, the numbers 1 through 25 are used along the north border to designate from west to east each

15-minute interval of longitude. Thus, the capital letter and the number that follows it designate a 15-minute quadrangle which is further subdivided into four 7½-minute quadrangles by using lower case letters "a", "b", "c", and "d" to represent the northwest, northeast, southwest, and southeast quarters, respectively.

The second part of the well-location number consists of a four-digit number that identifies the northwest corner of a one-hundredth square mile area (6.4 acres) within any 7½-minute quadrangle map. The first two digits refer to the number of tenths of a mile between the northern boundary of the 7½-minute quadrangle map and the northern boundary of the one-hundredth square mile area containing the well site. Similarly, the last two digits refer to the distance between the western boundary of the 7½-minute quadrangle map and the western boundary of the one-hundredth square mile area containing the well site. Thus, a well with the location number E2b-0804 is situated between 0.8 and 0.9 miles south and between 0.4 and 0.5 miles east of the north and west boundaries, respectively, of the 7½-minute quadrangle map designated "E2b", which is the Greenfield 7½-minute quadrangle.

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The cooperation, information, and access to private property, which were provided by numerous individual land owners and by companies engaged in manufacturing or in producing mineral products and fuels, are gratefully acknowledged.

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The Pittsburgh District, Corps of Engineers, U. S. Army, provided detailed information on the nature of the sediments filling the buried valleys at various locations in northwest Pennsylvania.

Acknowledgment is made also to D. W. Greenman, C. W. Poth, and T. E. Hendrix, who did geologic-reconnaissance work in the area; and to T. Balmer, R. A. McCullough and W. C. Roth, who collected hydrologic data.

GEOGRAPHY

Topography and Drainage

The Neshannock quadrangle is in the glaciated section of the Allegheny Plateau. The surface topography is that of a hilly upland cut deeply by the valleys of the Mahoning and Shenango Rivers and Neshannock and Lackawannock Creeks. The major streams presently flow southward on broad flat flood plains formed on bedrock, glacial outwash, and lake (?) deposits that are locally more than 200 feet thick. Along the flanks of the major valleys, and locally in the uplands, many terraces, irregular hills, and poorly drained depressions are formed on deposits of sand and gravel representing kames, kame terraces, and valley-train deposits.

Most of the upland area is covered by glacial till, and the topography is characterized by irregular hills, and depressions. In the northeast part of the quadrangle, where swampy areas are common, there are a few scattered small ponds. The average local relief in the uplands is about 100 feet.

The lowest point in the area is at the southern border where the Mahoning River leaves the quadrangle at an altitude of about 775 feet above msl (mean sea level). The highest point in the area, 1 mile north of Hoagland, is 1,392 feet above msl, giving a maximum relief in the area of 517 feet.

Local relief seldom exceeds 350 feet from the upland surface to the flood plain of the major streams.

The minor stream drainage has a deranged pattern, because it formed on the uneven surfaces exposed by the retreating glacier.

Climate

The climate of the Neshannock quadrangle is moist and temperate. The yearly average temperature is close to 50°F, and the total yearly precipitation is about 40 inches. The temperature during the winter months averages approximately 30°F, and occasionally falls below 0°F. The summer temperature averages about 70°F, and occasionally rises above 95°F. Precipitation is well distributed throughout the year. Movement of air across the Great Lakes produces a moderate amount of snowfall during the winter months.

The average growing season is approximately 145 days; generally, the first frost occurs early in October, and the last frost occurs near the middle of May.

POPULATION

The urban areas of Sharon and New Castle each lie partially within the region covered in this report. The city of Sharon has a population of approximately 25,000; its suburbs in Pennsylvania—including the city of Farrell, the Boroughs of Sharpsville and Wheatland, and the suburban districts in Hickory Township—have a total population of about 30,000. Its suburbs in Ohio contain an additional 9,000 persons. The city of New Castle has a population of approximately 45,000, and its suburbs have a total population of about 25,000.

The population of the Neshannock quadrangle, exclusive of the Sharon and New Castle urban regions, is about 25,000. The largest centers of population outside of the Sharon and New Castle areas are New Wilmington, with a population of roughly 2,200, and West Middlesex, with a population of about 1,300.

MANUFACTURING AND AGRICULTURE

Outside of the Sharon and New Castle urban areas, most of the Neshannock quadrangle is an agricultural area. The climate favors diversified agriculture, and the principal products include livestock, dairy products, apples, peaches, wheat, corn, and potatoes.

The principal industries of the Sharon area are the manufacture of electric transformers, the manufacture of steel, and the fabrication of steel products. The commodities manufactured in the New Castle area include ceramic products, steel products, industrial machinery, bearings, explosives, batteries, and plastic products.

WATER SUPPLY

More than 2 billion gallons of water per year are used in the Sharon and New Castle urban areas. Most of this is pumped from the Shenango River. Throughout the remainder of the Neshannock quadrangle, ground water is the dominant source of water supply. The communities of New Wilmington, West Middlesex, Pulaski, and Volant rely on ground water for their municipal supplies. Individual wells and springs supply most of the farms, homes, schools, and other establishments in the rural areas.

MINERAL PRODUCTS AND FUELS

The mineral resources of the area being utilized in 1961 include oil, limestone, coal, fire-clay, sandstone (for refractory purposes), ornamental building stone, sand, and gravel.

Before 1961, many small sandstone quarries supplied building stone and dimensioned block for refractory furnaces. Small deposits of siderite and bog-iron ore were mined for use in the charcoal furnaces common in the area in the mid-19th century. The existence of these deposits is of little more than historical interest at present. Exploration for oil and gas in the area began in 1861 along the Mahoning River (White, 1879, p. 201), where small quantities of oil were obtained from the Berea Sandstone. Some oil has been produced from the Berea Sandstone in the northern extension of the Bessemer pool near Hillsville, and some was being produced from the "Hundred-foot" Sand, near Volant, (east of the Neshannock quadrangle) in 1961. Gas has been produced from the Cussewago Sandstone near Mount Jackson and Gibsondale, just south of the Neshannock quadrangle.

GEOLOGY

STRATIGRAPHY

The stratigraphic nomenclature currently used for the Mississippian and Pennsylvanian rocks in northwest Pennsylvania is based on the publications of the Second Pennsylvania Geological Survey and has been slightly redefined for purposes of this report, so that all rock intervals are included within the named formations that have been used in the area in the past. This compromise involves the grouping in one formation of genetically unrelated strata representing different environments of deposition—such as fluvial, deltaic, paludal, marginal marine, and marine.

It would be inappropriate to suggest a major revision of stratigraphic nomenclature for the Neshannock quadrangle at this time for the following reasons: (1) unanimity of opinion is lacking on the classification of cyclically deposited coal-bearing strata, and this report deals largely with such strata; (2) this report is primarily concerned with the sandstone aquifers and intervening shale units of the Pottsville Group; (3) beds of coal and limestone observed in the field were indispensable in correlation of units, but the subdivisions of the shales, coals, and limestones were not studied in detail; and (4) the bedrock formations are masked by a veneer of glacial deposits, outcrops are rare, and much of the correlation of lithologic units is based on data from drillers logs.

The stratigraphy of the Mississippian rocks in the Neshannock quadrangle is comparatively straightforward, in that stratigraphic units are based on characteristic lithologic homogeneity within formations. Contacts between units are sometimes arbitrary because it is necessary, in some places, to select an arbitrary point of dominant change in lithology in a gradational sequence of beds. Correlation of units is based on lithology and stratigraphic position in relation to known marker beds.

The Pottsville Group was referred to in early reports as the "Seral Conglomerate" or "Conglomerate" measures and was subdivided, on a lithologic basis, into the Sharon Conglomerate, the lower Connoquenessing, upper Connoquenessing, and Homewood Sandstones, and the Sharon, Quakertown, and Mercer Shales. In this report these units are grouped into the following formations: The Sharon Formation, containing a lower conglomerate member and an upper shale member; the Connoquenessing Formation, locally divisible into a lower sandstone member, a middle shale member, and an upper sandstone member; the Mercer Formation; and the Homewood Formation, which is locally divisible into a lower sandstone member, and an upper shale member.

In this report, the formal subdivision of the Pennsylvanian System in the Neshannock quadrangle is based on a mixture of several concepts regarding stratigraphic nomenclature of lithologic units. One of the concepts is that of the coal group, as used in early reports; another is the grouping of beds according to cycles of deposition. The nomenclature used by White (1878) was based on the work of the First Pennsylvania Geological Survey. Concerning this nomenclature, Lesley (1879, p. XXVI) wrote:

> The number of groups (or series as they were first called) remains the same in 1879 that they were in 1839. Even the number of beds has not been increased or diminished; they have only been converted from sporadic and local to systematic and persistent beds; and this has merely increased the number of named beds.

Minor changes were made in subsequent reports by White (1880-1881) as new information made it possible to define and correlate more precisely units in the Pottsville and Allegheny Groups. Since White's work, changes in nomenclature have been minor. The principal changes were the adapting of White's nomenclature to conform to rules of classification and nomenclature of rock units (Ashley and others, 1933) and the changing of the top of the Pottsville Group from the top of the Homewood Formation to the base of the Brookville coal or its underclay.

The subdivision of the Allegheny Group (the "Lower Productive Coal Measures" of early reports) was based on coal groups, which were defined as extending from the base or top of one economic bed to the base or top of some other economic bed higher in the stratigraphic section, and including all the intervening strata—regardless of lithology.

The units so defined in this report are the Clarion Formation and the Kittanning Formation. The Clarion Formation extends from the base of the Brookville coal or its underclay to the base of the Vanport Limestone (early reports included the Vanport in the Clarion Coal Group). The Kittanning Formation extends from the top of the Vanport Limestone to the top of the upper Kittanning coal bed. The Kittanning is divided into three members, the boundaries being placed at the top of the lower Kittanning and middle Kittanning coal beds.

The system of nomenclature based on the arbitrary grouping of strata that lie between more important economic horizons into units, here referred to as formations and members, was adequate and useful in the early reports for outlining economic units and for stratigraphic discussion. In summary, it served the purposes of the First and Second Pennsylvania Geological Survey. This system of nomenclature has perhaps hindered the understanding of the genesis and relationship of the sedimentary rocks included within the coal groups. Futhermore this system makes geologic mapping almost impossible—even in areas of good exposures—because the economic beds that form the stratigraphic boundaries are not continuous.

Because the Vanport Limestone was absent in most of the Punxsutawney quadrangle, Ashley (1926, p. 29) placed the base of his Kittanning Formation at the base of the lower Kittanning coal or its underclay. By so doing, he included strata within the underlying Clarion Formation that were considered to be Kittanning in that part of Pennsylvania west of the Punxsutawney quadrangle, where the Vanport is present and where the base of the Kittanning has long been placed at the top of the Vanport.

Williams (1959 and 1960) used Ashley's (1926) terminology for the lower part of the Allegheny Group in parts of northwestern Pennsylvania, where the Vanport Limestone is present. Williams (1960, p. 190, Fig. 2) showed units long referred to as the lower Kittanning Sandstone and the Vanport Limestone as minor subdivisions of the Clarion Formation.

The Vanport Limestone is one of the most persistent, prominent, and lithologically distinctive units of the Pennsylvanian Series in western Pennsylvania. It is a unit that has been used since 1837 (Lesley, in White 1879, p. XXIV) as a key stratigraphic bed. In later reports, it has served as a prominent marker bed for structural contouring.

Recent studies of the stratigraphy and depositional environment of Pottsville and Allegheny rocks, by Williams (1957, 1959, 1960), Ferm (1957), and Degens, Williams, and Keith (1958), made significant contributions to the understanding of the regional relationships of the environmental zones and the paleogeography of the Pennsylvanian Period. The major conclusion of these investigations are summarized by Ferm and Williams (1960, p. 496-497) who concluded that the major coals represent breaks in sedimentation and are, therefore, good stratigraphic boundaries. According to Ferm and Williams, the intervals between principal coals could be subdivided on the basis of minor coal, limestone, and ironstone beds into detrital rock units of two types, as follows: (1) a lower, lithologically simple type of limited areal extent and (2) an upper, lithologically complex type of wide area extent. They concuded also that these two types, bounded by principal coals, could be considered as records of cyclic sedimentation.

The conclusion of Ferm and Williams that the prominent coal beds of the Allegheny Group are good stratigraphic boundaries is in accord with long established stratigraphic nomenclature of northwestern Pennsylvania. However, the prominent coal beds of one area are not necessarily the prominent coal beds of other areas; basing stratigraphic boundaries on coal beds accordingly creates problems in local areas in detailed mapping of lithologic units when a number of the coals are poorly developed.

For purposes of outlining units of interest in hydrology, a system of stratigraphic nomenclature based on various sandstone units throughout the section would be more useful than a system based on coal beds. The cyclothem, as described by Weller (1930) and Wanless and Weller (1932), provides such a system. Objections to the use of cyclothems as a basis for outlining stratigraphic units in the Neshannock area are as follows: (1) The sandstone units, which would form the base of the cyclothems, are not lithologically distinctive. (2) They are discontinuous and tend to be superimposed in successive cycles within linear belts within which intervening marker beds are generally missing by erosion. (3) In areas outside of the linear belts of well developed sandstone, the individual sandstone bodies tend to pinch out or cannot be traced. As a consequence, the cyclothems are well defined in only part of the area.

In the past, formal stratigraphic names have been applied to prominent sandstones, one limestone, and one shale of the Pottsville and Allegheny Groups. Other named subdivisions of beds have been used informally or considered as economic units—not formal stratigraphic units. Figure 2 summarizes the use of stratigraphic and economic terms used in the past for the Allegheny and Pottsville Groups in the Neshannock quadrangle and shows the terminology used in this report.

SEDIMENTARY ROCKS NOT EXPOSED IN THE AREA

More than 8,000 feet of Mississippian, Devonian, Silurian, Ordovician and Cambrian sedimentary rocks were penetrated in an exploratory oil well drilled about 5 miles north of the Neshannock quadrangle. Detailed information on these strata is given in a well-sample record by Wagner (1958). Because the Cussewago Sandstone is the oldest fresh-water-bearing formation in the area, and because no new information on these strata was collected, strata below the Riceville Shale (which underlies the Cussewago) will not be described in this report. In this report it is assumed that the thickness of strata below the Riceville does not change between the deep well and the Neshannock quadrangle.

The Riceville Shale, Cussewago Sandstone, Bedford Shale, Berea Sandstone, and Orangeville Shale do not crop out in the Neshannock quadrangle. Descriptions of these units are taken largely from well logs, I. C. White (1879, 1880, and 1881) and Pepper and others (1954).

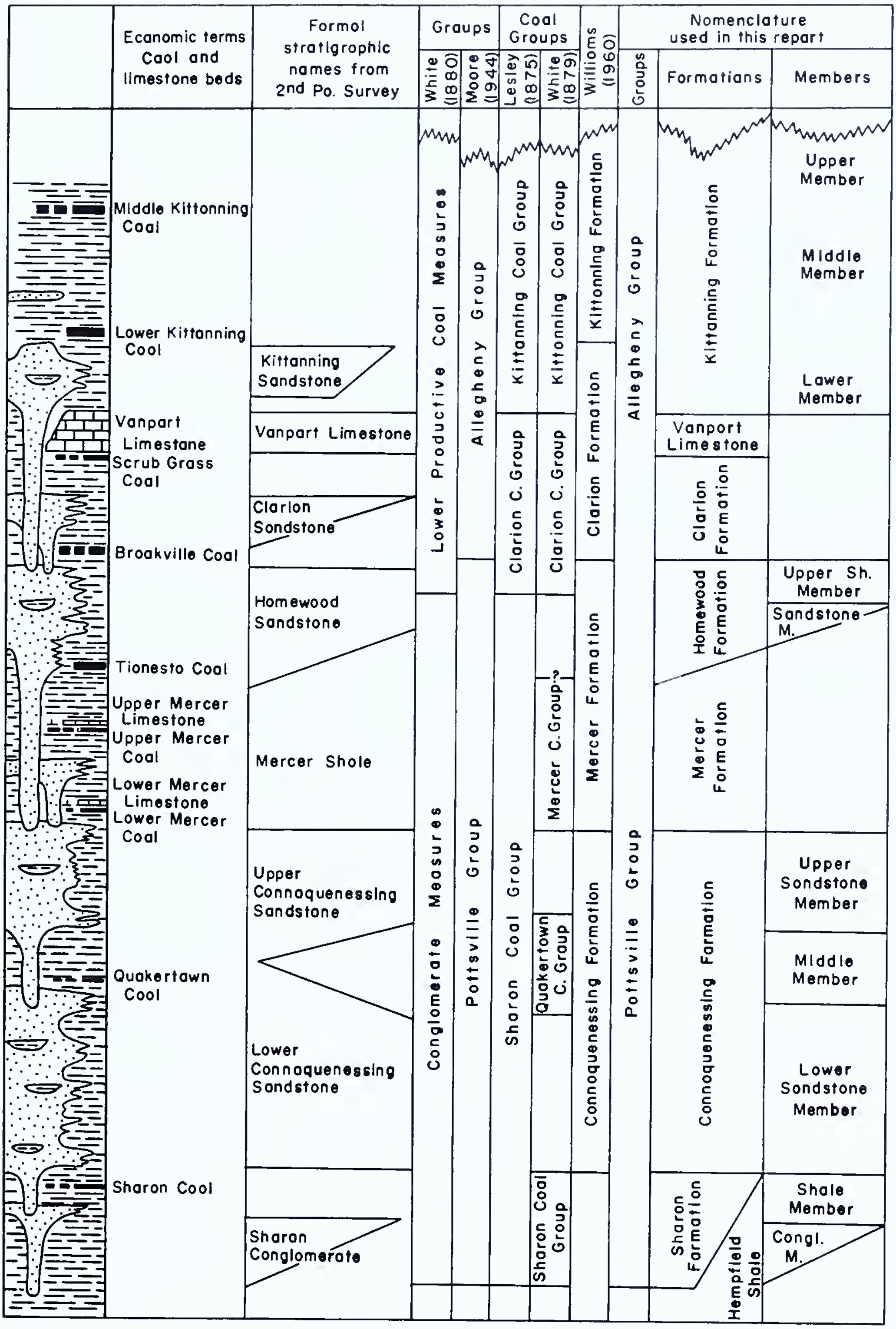

Figure 2. Past and current use of stratigraphic and economic terms for Pennsylvanian rocks in northwestern Pennsylvania.

Devonian System

Riceville Shale

The Riceville Shale, of Late Devonian age, was named by I. C. White (1881, p. 97-98) for a sequence of very fossiliferous, drab or bluish-gray sandy shales and shaly sandstones exposed in a bluff west of Riceville, northeastern Crawford County, Pa., 44 miles northeast of the Neshannock quadrangle. White (1881, p. 97-98) described the Riceville as containing no black or red layers and as extending from the "* * * Cussewago Sandstone down to the First oil sand of the Venango Group, a distance of say 80 feet * * *."

Pepper and others (1954, p. 17) described the Riceville as consisting of white, light-gray, tan, and light-brown fossiliferous siltstones and intercalated ash-gray silty shales and mudstones. He reported that the thickness of the unit ranged as much as 15 feet from that described by White, because of erosion that took place before the Cussewago Sandstone was deposited.

Information concerning the Riceville Shale in the Neshannock area is derived mostly from the few available records of churn-drill holes that were drilled in search of oil and gas. Water wells in the northwestern part of the area have penetrated only 15 to 20 feet into the Riceville after passing through the Cussewago Sandstone, which is a major fresh-water aquifer in that locality.

There is some question of the propriety of extending the term "Riceville" to include the sequence of gray and red siltstone and shale beds referred to by the well drillers as "slate" or "shale and shells", because the base of the unit is locally indefinite where the Hundred-foot sand is not present or recognized by the well driller. In the vicinity of Sharon, 3 wells drilled for oil and gas encountered 300 to 310 feet of light blue, gray, and gray and red shale; the upper 75 to 150 feet of this shale sequence is presumed to represent the Riceville Shale. Some (perhaps more typical) well logs show the Riceville Shale interval to be 75 to 150 feet thick, the upper 10 to 40 feet of which is gray and the lower part of which is red shale or red shale and siltstone.

Mississippian System

Cussewago Sandstone

The Cussewago Sandstone, of Mississippian age, was named by I. C. White (1881, p. 94-96) for exposures along Cussewago Creek Valley, Crawford County, Pa. White originally applied the name Cussewago to a shale and local limestone unit as well as to the sandstone. The name

"Cussewago" is now restricted to the sandstone unit. Because White's type locality for the Cussewago is somewhat indefinite, deWitt (1946) redefined the unit as "The typical friable greenish-yellow to greenish-brown quartz sandstone found below the Bedford Shale at White's (1881, p. 204) Bartholomew section."

As defined by deWitt (1946) the Cussewago Sandstone lies between the Riceville Shale and the Bedford Shale.

Information concerning the Cussewago in the Neshannock quadrangle is derived from logs of water wells in the northwestern part of the area, along the Shenango River from Pulaski to Sharon, and from records of wells drilled for oil and gas throughout the rest of the area.

The Cussewago Sandstone consists of from 20 to 100 feet of gray to white sandstone. It is presumed to be poorly cemented because well drillers report that it can be drilled easily by cable-tool methods. The grain size of the sand increases as the depth increases, and the lower beds generally contain pebbles.

The Cussewago Sandstone was shown to be a continuation of the Murrysville sand of the subsurface by Demarest (1946), who traced the Murrysville sand to the outcrop and found it to be identical to the Cussewago. A variety of names have been applied to the Cussewago by those engaged in oil and gas exploration. In addition to being called the Murrysville sand it has been referred to as the gas sand, Berea, and second Berea. Also, some drillers' logs of water wells in the northern part of the area have referred to the Cussewago as the Mountain sand, White sand, or White Mountain sand.

The altitude of the top of the Cussewago ranges from about 700 feet above msl in the northwestern part of the quadrangle to about 460 feet above msl along the southern boundary of the quadrangle. In the northeast corner of the area, from Wheatland north, the Cussewago dips to the southeast at 50 feet per mile. Throughout the rest of the quadrangle it has a southerly dip of about 15 feet per mile. The Cussewago is 10 to 60 feet below the Berea Sandstone, 260 to 280 feet below the Shenango Formation (Slippery Rock), 500 to 580 feet below the lower limestone bed of the Mercer Formation, and 610 to 670 feet below the Vanport Limestone.

Bedford Shale

The Bedford Shale was named by Newberry (1870, p. 21) for exposures along Tinkers Creek near Bedford, Bedford Township, Cuyahoga County, Ohio. The Bedford at its type locality was described by deWitt (1951, p. 1354) as consisting of about 85 feet of light-gray silty shale, many thin platy siltstones, and some hard discoidal limy nodules. The Bedford Shale was traced eastward from its type locality into Crawford County, Pa. by deWitt, who noted that it thinned eastward but maintained its characteristic lithology.

The Bedford Shale in the Neshannock area is the unit 10 to 60 feet thick, lying between the Cussewago Sandstone and the Berea Sandstone, that is usually logged as gray shale.

Berea Sandstone

The Berea Sandstone, of Mississippian age, was named for exposures of a drab, 50-foot thick sandstone at Berea, Ohio, by Newberry (1870). Using well logs, Demarest (1946) traced the Berea eastward from its type locality into northwest Pennsylvania. Using surface outcrops and core drill records, de Witt (1951) traced the Berea into Crawford County, Pa. He noted that the Berea changed progressively from a typical fine-to medium-grained sandstone, at its type locality, to a siltstone that merged into intercalated siltstones, silty mudstones, and silty shale of the Shellhammer Hollow Formation in the vicinity of Meadville, Pa.

The regional relationships of the Berea, Bedford, and Cussewago Sandstones are described in detail by de Witt (1951) and Pepper and others (1954).

The Berea Sandstone, where well developed in the southern part of the Neshannock quadrangle, is a 10- to 40-foot thick unit of gray sandstone, the base being 10 to 60 feet above the top of the Cussewago Sandstone. Northward from the southern part of the quadrangle, the Berea intertongues with beds of shale and siltstone and becomes unrecognizable in well logs—except along the western margin of the area where, at Wheatland and Sharon, thin light-gray sandstone beds are recorded where the Berea should be. North of Sharon the Berea has generally not been distinguished in well logs, and the combined Berea and Bedford interval has usually been logged as gray sandstone and shale, or shale and shells.

Orangeville Shale

The Orangeville Shale was named by I. C. White (1880, p. 63) for an exposure along Pymatuning Creek, at Orangeville, Pa. The exposure was composed of light gray shale and medium gray silty mudstone, about 75 feet thick, that contained beds of siltstone 3 inches to 1½ feet thick and beds of siderite 1 to 3 inches thick. The silty mudstone was stained with a mottling of blackish red, yellow, and yellowish orange.

The Orangeville Shale is about 60 feet thick along the southern part of the area and about 70 feet thick at Sharon. It overlies the Berea Sandstone and underlies the Sharpsville Sandstone. The boundaries of the Orangeville are somewhat indefinite in parts of the Neshannock quadrangle because either or both the underlying or overlying formations are unrecognizable in well logs or electric logs.

Rocks Exposed in the Area

Mississippian System

Sharpsville Sandstone

The Sharpsville Sandstone was named by White (1880, p. 62) for a sequence of alternating layers of very fine-grained sandstone and shale exposed along the Shenango River at Sharpsville, Pa., which is 1 mile northeast of Sharon, Pa. In a gully on the west side of Pine Hollow Run, 1 mile north of Neshannock quadrangle and 1 mile east of Sharpsville, 60 feet of Sharpsville Sandstone is exposed. The Sharpsville is here very fine-grained planar-bedded sandstone containing a thin calcareous layer about 25 feet above its base. It is light to medium gray or yellowish gray and weathers grayish brown. Individual beds range in thickness from 1 inch to 1½ feet. Interbeds of shale are not common in this exposure, but they are common in other exposures in the vicinity. Only the upper part of the Sharpsville Sandstone is exposed in the Neshannock quadrangle.

At Pine Run, in Sharon, Pa., 20 feet of the Sharpsville is exposed. At this exposure the Sharpsville consists of very fine-grained light-gray sandstone in laminated planar beds 1 to 2 feet thick, intercalated 3-inch beds of gray shale, and occasional thin beds of siderite. The sandstone weathers locally to thin flags and is overlain by interbedded shale and siltstone.

The Sharpsville Sandstone can be identified from the electric log of well Mr-925, which is 1½ miles east of Hickory, Pa., near the northern edge of the Neshannock quadrangle and 1½ miles southeast of the type area of the Sharpsville. The Sharpsville appears to be composed mostly of shale and beds of sandstone 1 to 3 feet thick in a 30-foot interval that lies 95 feet below the Shenango Sandstone. The Sharpsville may also be identified from the logs of well La-911, which was drilled for oil and gas 1½ miles northeast of New Bedford; here the Sharpsville lies 184 feet above the Cussewago Sandstone and 75 feet above the Berea Sandstone.

Logs of wells drilled just south of the Neshannock quadrangle—in the Bessemer pool and Big Run pool, near Gibsondale—generally show a 25-to 60-foot sandstone. This sandstone, referred to as the Amber sand, is 50 to 70 feet above the Berea Sandstone, 110 to 140 feet above the Cussewago Sandstone, and about 75 feet below the "Slippery Rock sandstone," which is here considered to be a subsurface equivalent of the Shenango Formation. This sand referred to in the logs as the Amber sand is considered to be the subsurface equivalent of the Sharpsville Sandstone. Obviously, the terms "Amber" and "Berea" have not been used consistently for the same stratigraphic units. In those well logs that do not record the sandstone believed to be the subsurface equivalent of the Sharpsville, the term Amber sand is misapplied to the Berea Sandstone and the term "Berea" is misapplied to the Cussewago Sandstone.

The Sharpsville is not continuously traceable throughout the Neshannock quadrangle by the use of well logs, and it is poorly defined in the electric logs of well Mr-956, at West Middlesex, and well La-443, about 1 mile east of Coaltown. Strata in the position occupied by the Sharpsville are usually recorded in well logs as sandy shale or shale and shells and are not usually differentiated from the overlying Meadville Shale or underlying Orangeville Shale, the other formations of the Cuyahoga Group.

Meadville Shale

The Meadville Shale, in the Neshannock area, is typically a 60- to 90-foot unit of interbedded gray shale, silty shale, and thin beds of siltstone and very fine-grained sandstone. Nodules and thin layers of siderite are common locally, and shell impressions are occasionally found on the undersurfaces of the siltstone beds. The formation was referred to by White (1880, p. 61), in his report on Mercer County, as the Crawford Shale.

The term "Meadville Group" was first used by White (1881, p. 68), in his report on Crawford and Erie Counties, in place of the Crawford Shale of Carll (1880, p. 82), because the original definition of Crawford Shale by Carll included (according to White) "all the soft measures pierced by the drillers before reaching the First Venango Oil Sand", which included all the strata now assigned to the Mississippian System.

The Meadville Group of I. C. White included what is now the Meadville Shale, Sharpsville Sandstone, and Orangeville Shale—the equivalent of the presently accepted definition of the Cuyahoga Group in northwest Pennsylvania. White substituted the names "Crawford" and "Meadville" for Cuyahoga, because the Cuyahoga (as then defined) included the Shenango Sandstone and Shenango Shale of White, and there was a possibility (White, I. C., 1880, p. 59) "That the Shenango Sandstone is the Pennsylvania representative of the lower part of the Ohio conglomerate (Sharon conglomerate); which would confine the name Cuyahoga Shales to the lower shales and leave the upper shales without a name." As used in 1961, the Cuyahoga Group in northwest Pennsylvania excludes the Hempfield Shale and the Shenango Sandstone of White; the name Meadville Shale is used for the upper shale formation of the Cuyahoga Group, which includes the beds between the base of the Shenango Formation and the top of the Sharpsville Sandstone.

The lower boundary of the Meadville Shale cannot be recognized in many well records throughout the Neshannock quadrangle, because the underlying Sharpsville Sandstone is either poorly developed or is not noted in well logs. The upper boundary is placed at the base of the Shenango Sandstone, which is the Slippery Rock sand of the well drillers.

The Meadville Shale includes a thin but persistent bed of calcareous very fine-grained sandstone that was recognized and traced by the First Pennsylvania Geological Survey (Rogers, 1858, 1, p. 584) from Meadville, Pa. south to Sharon, Pa. White (1880, p. 61) reported that "a remarkable shell bed" occurred 25 feet below the top of the Meadville Shale at Brookfield, Ohio, 3 miles west of Sharon, Pa., and referred to it as the Meadville Limestone. White did not mention recognizing the upper limestone bed of the Meadville elsewhere in his report on Mercer County, and the bed was not identified in the Neshannock quadrangle during the present investigation.

Exposures of the Meadville Shale in the Neshannock quadrangle are restricted to the vicinity of Sharon, Pa., where a local steepening of the regional dip to the southeast brings the Meadville above the level of the Shenango River. The Meadville Shale has been identified elsewhere in the Neshannock quadrangle by means of drillers' logs.

The best exposures of the Meadville are along Pine Run and U. S. Route 62 bypass, in Sharon, Pa.

Shenango Formation

The Shenango Formation was first named the Shenango Sandstone by I. C. White (1880, p. 59-60) for outcrops at several places along the Shenango River; no specific type locality was designated. The Shenango was described by White as a coarse-grained, generally poorly cemented, brownish-white rock, that ranged in thickness from 2 to 25 feet, and contained large quantities of siderite nodules, pebbles from the underlying Meadville Shale, and, locally, abundant shells and fish remains.

The interval occupied by the Shenango in the Neshannock quadrangle is occupied by both shale and sandstone in nearby areas east of the Neshannock quadrangle (Sherrill and Matteson, 1939, p. 7-8; 1941, p. 12-13) (Dickey and others, 1943, p. 15-18). For this reason, the name Shenango Formation is used in this report.

Descriptions of the Shenango by White (1880) are almost entirely for sections measured west and north of the Neshannock quadrangle. Some of these sections are reviewed here for purposes of illustrating changes in the thickness and lithology of the Shenango. The Shenango was reported to be 7 feet thick at Whittacker Falls, Ohio, 2½ miles southwest of Sharon, Pa. (White 1880, p. 122). White (1880, p. 123) described the Shenango as being only 3 feet thick and "a perfect mass of shell and plant remains" at Brookville, Ohio, 1 miles west of Whittacker Falls, Ohio. North of the Shenango River, 1 mile west of the northeast corner of Hickory Township, the Shenango was described by White (1880, p. 106) as being 15 feet thick and composed of coarse-grained sandstone, siderite nodules, and some fish remains. It was 20 feet thick half a mile below the Big Bend of the Shenango River (White 1880, p. 154). White's sections show at least a local westward thinning of the Shenango.

The Shenango Formation in the Neshannock quadrangle is dark olive brown on weathered surfaces and yellowish orange to light gray in fresh exposures. It is a fine- to medium-grained, planar- to cross-bedded sandstone 7 to 60 feet thick. At its base there is generally a conglomeratic sandstone that ranges in thickness from 0 to 2 feet and lies disconformably on gray shale and siltstone of the Meadville Shale. The pebbly material in the conglomeratic sandstone averages one-half to three-quarters of an inch in diameter and is composed of shale, siltstone, and siderite in a matrix of medium-grained calcareous sandstone. A 1- to 3-foot bed of hard calcareous sandstone, which weathers to smooth curved surfaces, was noted near the base of the Shenango Formation at several exposures south of Sharon, Pa.

The contact between the Shenango Formation and the overlying Hempfield Shale is drawn at the top of the massive sandstone or at the base of alternating sequences of sandstone and shale. It is exposed at only a few places in the Neshannock quadrangle. The maximum observed relief on the contact between the Shenango Formation and the Meadville Shale is about 15 feet.

The Shenango Formation is particularly well exposed near where Buchanan Run enters the Shenango River flood plain, northeast of the village of Pulaski, Pa. Here it is 40 to 55 feet thick, the lower 20 to 35 feet of the formation consisting of predominantly planar, thin-bedded, locally flaggy, fine-grained sandstone. The variation in thickness is due to relief at the base of the unit. A conglomeratic calcareous sandstone 0 to 2 feet thick, containing pebbles of siderite and shale, occurs over the topographically high points of the pre-Shenango surface and is overlain by a cross-bedded calcareous sandstone 2 feet thick. The cross-bedding dips to the west. The topographically low points on the pre-Shenango surface are overlain by thin-bedded, fine-grained, flaggy sandstone. Imprints of shells were found on bedding surfaces 8 to 10 feet above the base of the formation over the topographic lows. A few feet below the top of the planar-bedded to flaggy part of the Shenango, the sandstone contains carbonaceous material and impressions of tree branches.

The upper 20 feet of the Shenango Formation at Buchanan Run is a fine- to medium-grained crossbedded sandstone. The lower surfaces of the sets of cross strata are planar to curved. The crossbedding dips gen erally westward. The Shenango Formation is rarely completely exposed in the Neshannock quadrangle although parts of it are exposed in lower reaches of many of the small tributaries to the Shenango and Mahoning Rivers.

Some of the stratigraphic features observed in Buchanan Run were observed in other exposures of the Shenango in the Neshannock quadrangle, but detailed correlation of the stratigraphic features is not possible with available information. Identification of the formation is based chiefly on stratigraphic position and the presence of calcareous sandstone beds and fossils.

The thinning of the Shenango to the west, as shown in Figure 3, suggests an easterly source for the Shenango, which is in agreement with conclusions drawn by Pelletier (1958, p. 106) for presumably equivalent strata farther east in Pennsylvania.

Hempfield Shale

The formation here referred to as the Hempfield Shale was first named Shenango Shale by White (1880 p. 59). In order to avoid using the same geographic name for more than one formation, Caster (1934, p. 14) proposed the name Hempfield Shale to replace White's Shenango Shale and restricted the usage of the name Shenango to the underlying sandstone.

The Hempfield Shale (Shenango Shale of I. C. White) was described by White (1880, p. 60) as a 36- to 50-foot unit of flaggy sandstone containing interstratified layers of shale and (rare) poorly preserved shell and plant impressions.

In the Neshannock quadrangle the Hempfield Shale is composed of gray shale, intercalated thin beds of fine-grained micaceous sandstone or siltstone, and thin layers of siderite nodules. The Hempfield ranges in thickness from 15 to 60 feet, but most well logs show it to be about 45 feet thick. The Hempfield Shale is thinnest under the sandstone channel deposits at the base of the Sharon Formation. Where the lower sandstone member of the overlying Sharon Formation is present or recognizable, in the northwest part of the area, the upper boundary of the Hempfield is well defined. Where the sandstone member of the Sharon is not present—but the Sharon coal is—the top of the Hempfield is placed at the base of the Sharon coal or at the base of the underclay, if it is present. Throughout most of the Neshannock quadrangle the Sharon coal, its underclay, and the sandstone member of the Sharon could not be identified; therefore, the top of the Hempfield was placed at the base of the lowest sandstone bed of the Connoquenessing Formation.

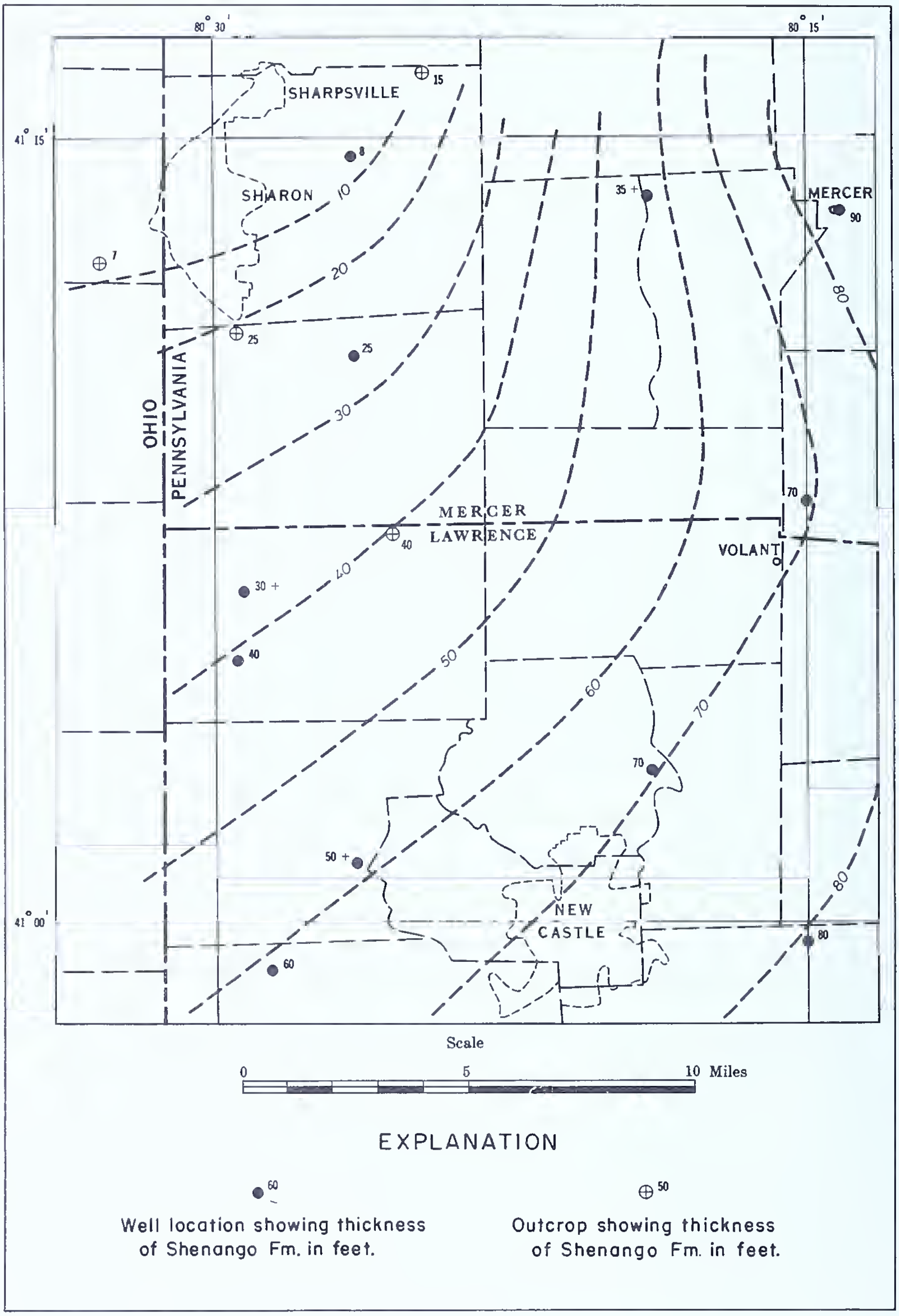

Figure 3. Isopach map of the Shenango Formation in the Neshannock quadrangle.

Pennsylvanian System

Pottsville Group

Sharon Formation

The Sharon Formation is here used to include strata referred to by White (1879, 1880, 1881) as the Sharon Conglomerate and Sharon Shales. It has long been considered the basal formation of the Pennsylvanian System in western Pennsylvania. The Sharon is designated as a formation consisting of a lower conglomerate member and an upper shale member. The usage of the term "formation" instead of "conglomerate" in the lithologic part of the formal name of the Sharon departs from current usage—as in Fuller (1955), where the Sharon Conglomerate refers to just the conglomerate member of the Sharon Formation of this report. Because the Sharon is poorly exposed in the Neshannock area, it would be inappropriate to suggest a new name for the Sharon Shale of White (1880, p. 51-58) at this time.

For purposes of description and mapping in this report, the base of the Sharon Formation has been placed at the base of the conglomerate member, where it is present. Where the conglomerate member is absent, the base of the Sharon Formation is placed at the base of the Sharon coal. Where both the Sharon coal and the conglomerate member are absent, the Sharon Formation cannot be defined and is included in the underlying Hempfield Shale or the overlying Connoquenessing Sandstone. The contact between the conglomerate member and the shale member could not be followed in mapping.

The Sharon Formation could be traced in only the northwest part of the Neshannock 15-minute quadrangle—essentially in the Sharon East 7½-minute quadrangle. Thin stringers of coal occur locally below the Connoquenessing Formation; because these thin stringers of coal and coaly shale could not be traced laterally in the Neshannock quadrangle, they are here included in the Hempfield Shale. This is in agreement with White (1879, p. 69) who stated: "In no portion of Lawrence [county] do we find any conglomerate or massive sandstone below the horizon of this coal but the Cuyahoga [Hempfield] Shale with its fossils extends up to the very base of the lower part of the Massillion [Connoquenessing] Sandstone." White (1879, p. 68) states, concerning the Sharon coal: "This celebrated bed which attains such immense importance in the county immediately north of Lawrence, has never been found of workable dimensions in the area [Lawrence County] we are considering * * * It comes indeed, to within a few rods of the county line, but it there suddenly thins away to a feather edge and disappears."

In summary, most of the information concerning the Sharon Formation that was gathered during this investigation is shown in Section A-A′

(Plate 2). This information was obtained mostly from well logs and reports from individuals concerning the depth to coal in mines. No exposure of the entire Sharon Formation was observed during this investigation, and the formation could not be traced away from Hickory and Shenango Townships, Mercer County, by means of well logs.

White (1880, p. 51-58) described rocks here included in the Sharon Formation as consisting of the Sharon shales, here referred to as the shale member of the Sharon Formation, and the Sharon conglomerate here referred to as the conglomerate member of the Sharon Formation.

Shale member.—The shale member of the Sharon was described by White (1880, p. 51-56) as a dark bluish-gray to light-gray shale and sandy shale containing thin layers and nodules of siderite. Several beds of coal less than 1 foot thick, which are considered to be "rider" veins to the Sharon coal (0 to 5 feet thick), occur near or at the base of the shale member. The shale immediately overlying the Sharon coal bed contains numerous impressions of plants and was referred to informally by White as the Sharon Plant Shales. The interval between the base of the Sharon coal and the top of the conglomerate member of the Sharon Formation was described by White as consisting of underclay and shale, which is missing in some places. Where the underclay and shale are missing, the Sharon coal rests directly on the conglomerate member. The thickness of the shale member of the Sharon Formation ranges from 0 to 50 feet but is typically between 10 and 30 feet.

No complete exposure of the shale member was seen during this investigation. One of the best partial exposures of this unit was found a quarter of a mile northeast of Hermitage, Hickory Township, Mercer County, where a small pit adjacent to Pine Hollow Run was dug to provide landfill. Here about 25 feet of the shale member is exposed, and approximately 20 feet of the conglomerate member can be seen in a continuous exposure in the adjacent stream valley. The contact between the shale member and the conglomerate member is sharp and irregular. Beds of black shale 1- to 13-feet thick, containing layers and nodules of siderite, overlie the conglomerate. The black shale is overlain by the Sharon coal bed, which is about 1 foot thick. The coal is overlain by 10 feet of dark gray shale. Relief on the Sharon coal bed is about 12 feet in a distance of 50 feet. The maximum local relief observed on the Sharon coal bed in the Neshannock quadrangle is about 40 feet. This relief is believed to result from excessive compaction of coal and shale, compared to that of the sand, giving the effect of the coal draping over the thick sandstone-filled channels in the conglomerate member. White (1880, p. 123) found the floor of the coal uneven at Brookfield, Ohio, 3 miles west of Sharon. He related it to "* * * piles of conglomerate, which often rise at an angle of 15° to a height of 20 to 30 feet * * *", and noted that the coal thinned over the topographic highs.

The Sharon coal bed was mined extensively in the northwest corner of the Neshannock quadrangle during the last half of the 19th Century. Many exposures of the Sharon coal bed in adits and mine shafts, combined with records of the mine operators, provided White (1880) with information on the Sharon coal and associated strata. Few new data have been recorded concerning the Sharon Formation and the Sharon coal since that time.

The importance of the Sharon coal in the economy of the Shenango Valley in the past can be appreciated from the following quotes from Eavenson (1952, p. 225): "Coal was found near Sharon probably as early as 1810 and actual mining began about 1835 * * * The coal had a different structure from most western Pennsylvania coal, it was laminated, split in flat blocks, very hard to break across the laminations. It was strong enough to stand the weight of the burden in the furnaces of those days and after 1849, for many years, all iron made in this locality, and some furnaces in Ohio, used raw coal for fuel. During the Civil War, the output of the County (Mercer)exceeded 2,500 tons per day, a considerable tonnage then." The following quotes from White (1880, p. 55) concern the reserves of the coal: "The quantity of Sharon coal remaining unmined is hard to calculate, because new areas of it are discovered every few years. But the best informed men in the Shenango Valley state, that more than half the known available coal has been extracted; that 25 or 30 years more mining will practically exhaust the known areas; and that, making a liberal allowance for areas to be discovered, and at the rate of production for the last 20 years, 50 years more will certainly exhaust the whole."

The estimates of coal reserves, made in about 1879, were fairly accurate, for in 1961 no Sharon coal had been mined for commercial use for several years in the vicinity of Sharon, Pa. The only place where the coal was mined in the few years preceding 1961 is a quarter of a mile northeast of Hermitage, where coal a little over 1-foot thick was uncovered by accident while shale and gravel were being strip mined for fill. A few tons of coal are mined yearly from this pit, for consumption by the property owner. Elsewhere in the Sharon area all vestiges of the once-important coal-mining industry are rapidly disappearing as the spoil piles are hauled away for use as road metal. Most of the mine openings have been filled in.

Conglomerate member.—White (1880, p. 56) described the conglomerate member of the Sharon Formation at Sharon, Pa., as being typically 20 feet thick and made up of two equal layers; the upper layer being a moderately coarse-grained white sandstone and the lower layer a conglomerate of loosely cemented pebbles in a matrix of bluish-gray sand.

The conglomerate member, where seen during this investigation, was a medium- to fine-grained, light-gray to white, quartz sandstone. The term "conglomerate" is retained for this unit, although no exposures of conglomerate were seen in the Neshannock quadrangle during this investigation. Exposures of conglomerate were reported by White (1880), and locally conglomeratic exposures of the member near Greenville, Pa., and in Turnbull County, Ohio, were reported by Fuller (1955, p. 173).

The conglomerate member was identified positively in only scattered outcrops in Hickory and Shenango Townships, Mercer County, Pa. The exposure of the conglomerate member of the Sharon near Hermitage, Pa., as shown in Section A-A′ (Plate 2), is interpreted as a cross-section of a channel-fill sandstone and is believed to be the southerly extension of a sandstone exposed 1½ miles north of Lamonts Corners, Pa., in the Sharpsville quadrangle. This channel-fill sandstone could not be traced farther to the south. East of the Neshannock quadrangle, a sandstone unit has been identified in the electric log of well Mr-944, at Mercer Pa., at the stratigraphic level of the conglomerate member of the Sharon. The conglomerate member of the Sharon could not be traced between Hermitage and Mercer, Pa.

Although the data are fragmentary there is strong suggestion that the conglomerate member in the northwest part of the Neshannock quadrangle occurs in shoestring-type sandstone bodies that fill channels. Fuller (1955, p. 174) suggests a deltaic or alluvial plain as the environment of deposition of the conglomerate member.

The Sharon Formation was studied extensively in northeast Ohio by Rittenhouse (1946), Bowen (1953) and Fuller (1955). The Sharon is quarried in that area as a source of high (96% SiO_2) silica rock for foundry sand, ferrosilica, and silica brick. The conglomerate member of the Sharon Formation in the area just west of the Neshannock quadrangle was described by Fuller (1955, p. 173) as consisting mainly of orthoquartzite having one known southerly trending conglomerate belt. Studies of stratigraphic features and physical composition led Fuller to believe that the Sharon had a northern source and, based on heavy mineral studies of Rittenhouse (1946, p. 1195), to conclude that the source of the Sharon in Trumbull County, Ohio was the same as that of the Olean Conglomerate.

The .conglomerate member of the Sharon Formation is not quarried in the Neshannock quadrangle at present, but it is quarried 9 miles north of the Neshannock quadrangle (near Greenville, Pa.) by the White Rock Silica Sand Company, for refractory, roadstone, filler, and foundry purposes.

Connoquenessing Formation

The name "Connoquenessing Sandstone" was applied by White (1878) to all the "massive rock" between the lower limestone bed of the Mercer Shale and the Sharon coal. White (1879, p. 63-64) described the Connoquenessing as follows: "we find it in Lawrence County split up into an upper and lower massive portion with a coal horizon in the center * * * we have accordingly termed the upper massive ledge the Upper Connoquenessing Sandstone from the fact that it forms the upper cliff rock along that stream between its mouth and Slippery Rock, and the lower massive member we have termed the Lower Connoquenessing Sandstone, because it is frequently seen along the bed of the same stream."

The coal between the upper and lower sandstone units of the Connoquenessing was named the Quakertown coal bed by White (1879, p. 65) for its occurrence in Quakertown Run, 1 mile northwest of Hillsville, Pa. White (1879, 1880) and DeWolf (1929) also used the name Quakertown to refer to the shales associated with the Quakertown coal bed.

The Connoquenessing is here called the Connoquenessing Formation and can be subdivided locally, for descriptive purposes, into three members: (1) an upper sandstone member, equivalent to the Upper Connoquenessing Sandstone of White (1879 and 1880); (2) a middle shale member, equivalent to the Quakertown coal and shale of White (1879, and 1880) and DeWolf (1929); and (3) a lower sandstone member, equivalent to the Lower Connoquenessing Sandstone of White (1879 and 1880). Lateral variations in the lithology of the Connoquenessing have been noted and emphasized in all previous reports describing the nature of this formation in northwest Pennsylvania.

The upper sandstone, lower sandstone, and middle shale members of the Connoquenessing are not uniformly developed in the Neshannock area. The sandstone members are best developed in poorly defined, generally northwest-southeast trending, overlapping, meandering, linear belts 4 to 5 miles wide, in which the Connoquenessing Formation is composed predominantly of sandstone. The middle shale member is most clearly defined along the flanks of the linear belts of thick sandstone. Within the linear belts of thick sandstone, the shale member is discontinuous and lenticular and cannot be traced reliably. In the areas between the linear belts of thick sandstone, both the upper and lower sandstone members are poorly defined and are represented by one or more units of sandstone 5 to 10 feet thick. In these areas the Connoquenessing Formation consists mostly of shale.

The lateral variations in the lithology of the members of the Connoquenessing Formation have not been mapped in detail in the field, but they are shown in cross-section in Plate 2. The local variation in lithology

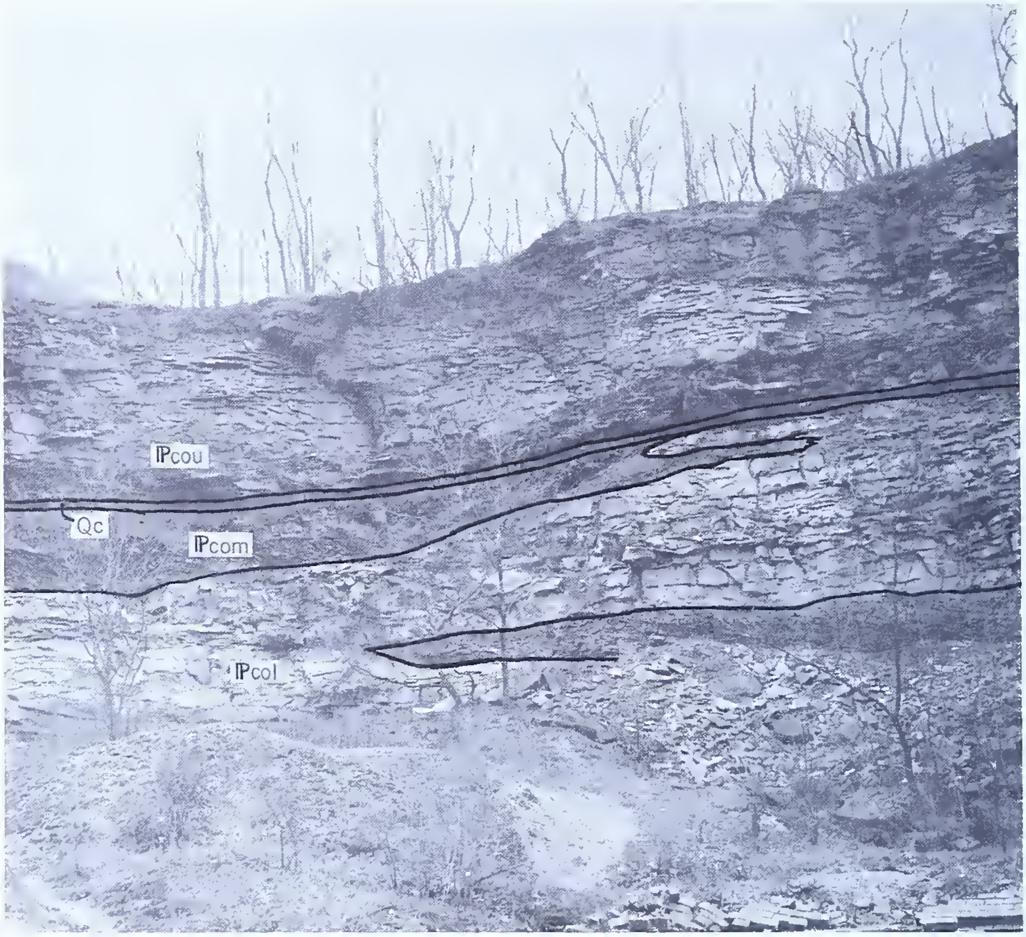

Figure 4. Exposure of the Connoquenessing Formation in a quarry half a mile north of Croton School at New Castle, Pa. IPcou, upper sandstone member; IPcom, middle shale member containing a black carbonaceous shale zone at top (Qc) representing the Quakertown coal bed; IPcol, lower sandstone member, containing a shale lens.

within one of the linear belts of thick sandstone is shown in Figure 4, where several shale lenses are shown. These lenses are considered as "shale plugs" filling channels of abandoned meanders.

The base of the Connoquenessing, for mapping purposes, has been drawn at the base of a sandstone unit believed to be continuous throughout most of the Neshannock quadrangle. It lies 140 to 150 feet below the lower limestone bed of the Mercer Shale and 240 to 265 feet below the base of the Vanport Limestone. In the northwest part of the Neshannock quadrangle, near Mercer, Pa., and in the northeast part of the quadrangle, the Connoquenessing is underlain by the shale member of the Sharon Formation. In the southern half of the Neshannock quadrangle, neither the Sharon coal nor the conglomerate member of the Sharon are known to be present. Their equivalents (if present) are included in the Hempfield Shale, which underlies the Connoquenessing Formation.

The contact between the Connoquenessing and the Mercer Shale is drawn on top of the upper sandstone member of the Connoquenessing Formation. In areas where the upper sandstone member is poorly developed or absent, the shale member is considered to extend up to the base of the Mercer Formation, and the contact is arbitrarily placed, for mapping purposes, 15 feet below the base of the lower limestone bed of the Mercer Formation.

The total thickness of the Connoquenessing in the Neshannock quadrangle, as measured in surface exposures, ranges from 100 to 180 feet.

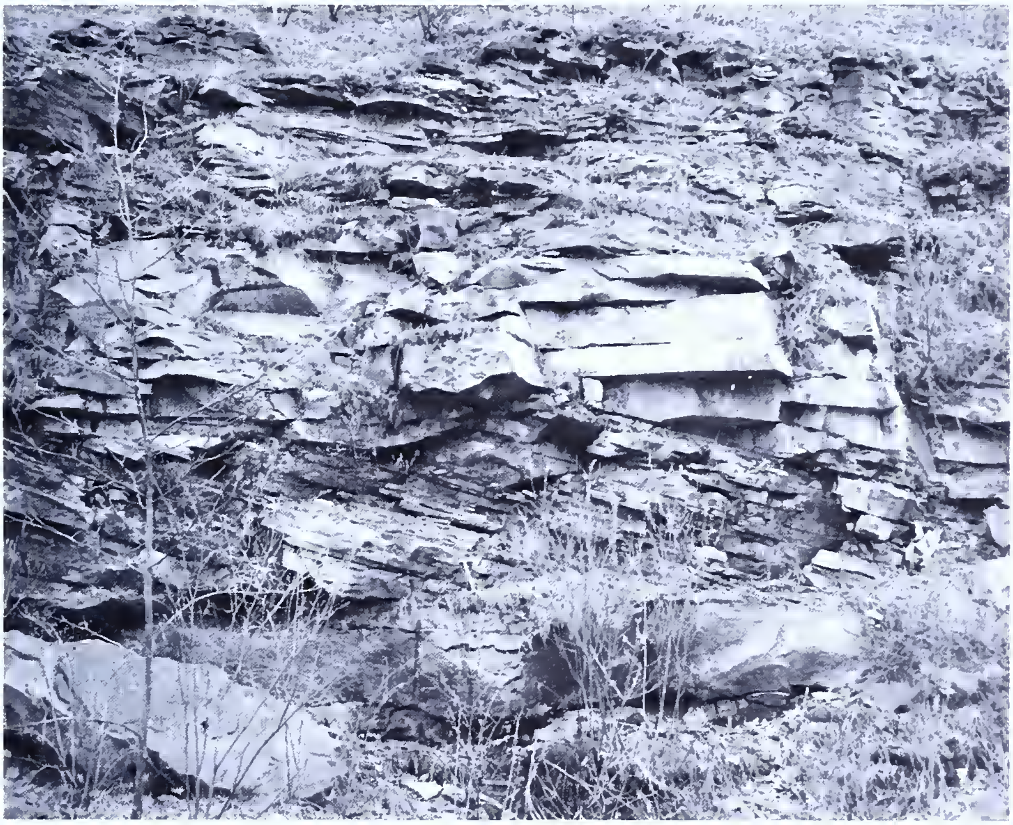

Figure 5. Lower sondstone member of the Connoquenessing Formotion north of Croton School, New Costle, Po., showing voriotions in bedding.

Lower sandstone member.—The lower sandstone member of the Connoquenessing Formation, in the quadrangle south of the Neshannock quadrangle, was described by DeWolf (1929, p. 56) as "a coarse-grained, white rock, usually massive or thick-bedded; in some places, however, it may be conglomerate or shaly. * * * The exposures of this bed range from 5 to 75 feet in thickness, averaging 40 feet where the development is not abnormal."

The lower sandstone member in the Neshannock quadrangle is exposed in many places along the tributaries to major streams. It is 5 to 80 feet thick, white, light-gray, or yellowish-white on fresh surfaces and pale brown to brownish gray on weathered surfaces. Where the lower sandstone member is well developed it consists of medium- to coarse-grained quartz sandstone in planar sets of cross strata, 1 to 6 feet thick, and planar-bedded, fine- to medium-grained, micaceous, quartz sandstone 0.1 to 2 feet thick and lenticular shale units (Figures 4 and 5). In exposures along Neshannock Creek in New Castle, Pa., where the lower sandstone member is well developed, the contact at the base of the member is disconformable and well defined, and the lower layers of the member contain pebbles of the underlying shale. Where the lower sandstone member is not well developed, it is predominantly planar bedded and fine grained. The contact between the base of the member and the underlying shale of the Hempfield or Sharon Formation is not always so well defined.

The dip direction of crossbedding in the lower sandstone member is variable. The directions of dip of the crossbedding range from northeast, through northwest, to southwest, but a few crossbeds dip east, southeast, or south. Resultant downdip direction of 27 measurements on crossbeds is north 70° west, as shown in Figure 8.

Middle shale member.—The middle shale member of the Connoquenessing Formation is poorly exposed in the Neshannock quadrangle. It is 0 to 70 feet thick and consists of gray to brown shale, a few thin beds of sandstone and siltstone, thin layers and nodules of siderite and the Quakertown coal bed, which is 0 to 3 feet thick. The Quakertown coal was named by I. C. White (1879, p. 65) for exposures about 1 mile northwest of Hillsville, Pa. It was mined on a very small scale, for local use, in a few parts of the quadrangle in the mid-19th century. Outcrops of this coal can still be seen at many of the localities described by White (1879, and 1880). In a few places black papery shale is associated with the Quakertown coal bed. Where the coal is absent, the black shale is considered as an indicator of the stratigraphic position of the Quakertown coal bed.

The contact between the middle shale member and the lower sandstone member is generally gradational. The upper boundary of the shale member is typically sharp and disconformable where the upper sandstone member is present. Where the upper sandstone member is not present, as in parts of Hickory Township, Mercer County; and Mahoning and Pulaski Townships, Lawrence County; the upper boundary of the middle shale member is considered to be 15 feet below the base of the lower limestone bed of the Mercer Formation.

Upper member.—The upper member of the Connoquenessing Formation was referred to by White (1880) and DeWolf (1929) as the Upper Connoquenessing Sandstone. White (1880, p. 46) described the upper member in Mercer County as "a tolerably coarse grayish-white sandstone." He mentioned also that it was locally conglomeratic. DeWolf (1929, p. 53-54) described the upper member as ranging in thickness from 5 to 84 feet and having an average thickness of 40 feet in the New Castle quadrangle, which is south of the Neshannock quadrangle. He described it also as being a variably bedded, generally coarse-textured sandstone that ranged from conglomerate to sandy shale. Both White (1880) and DeWolf (1929) mention localities where the Mercer Formation is absent and the Homewood Formation and upper sandstone member of the Connoquenessing form a continuous sequence of sandstone, and DeWolf (1929, p. 53) states that in places the upper member of the Connoquenessing "* * * is probably continuous with the Lower Connoquenessing Sandstone."

In the Neshannock quadrangle, the upper member of the Connoquenessing is a fine- to very coarse-grained, locally conglomeratic, quartz sandstone that includes lenticular units of shale. It is 0 to 70 feet thick, light gray, white or yellowish orange on freshly exposed surfaces and pale brown to brownish gray on weathered surfaces. The upper member is thin to thick bedded and composed predominantly of planar sets of cross strata but containing some massive planar beds. The direction of the crossbedding is about N. 40° W. The upper member is absent in the Neshannock quadrangle and in parts of Hickory Township, Lawrence County. The member is thickest in poorly defined, linear, meandering belts about 5 miles wide that overlap the belts of thicker sandstone in the lower member of the Connoquenessing Formation.

Mercer Formation

The name "Mercer" was first used as a stratigraphic name by Roger (1858, p. 474-477) for exposures at Hells Hollow, in East Lackawannock Township, Mercer County, Pa. He applied the term "Mercer Limestone" to the lower limestone bed of the Mercer Formation of current usage. The upper limestone bed of the Mercer was called Mahoning Limestone by Rogers and Upper Wurtenburg Limestone by Lesley (1875); these names were subsequently abandoned by White (1879, p. 57) to avoid confusion and to simplify the nomenclature. White substituted the name Upper Mercer Limestone for Roger's Mahoning Limestone and the name Lower Mercer Limestone for Roger's Mercer Limestone. He applied the name Mercer to all of the strata, including shale, coal, underclay, sandstone, and limestone, lying between the upper sandstone member of the Connoquenessing Formation and the underclay of the Tionesta coal, or—

where the Tionesta coal bed was absent—to the base of the sandstone member of the Homewood Formation. DeWolf (1929) defined the Mercer Formation in the same way. The Mercer Formation, as used in this report, applies to all the strata between the upper sandstone member of the Connoquenessing and the sandstone member of the Homewood Formation; as so defined, it includes the Tionesta or Homewood coal and Homewood shales of White and DeWolf.

The Mercer Formation in the Neshannock quadrangle has a maximum thickness of 90 feet and disappears locally where the sandstone members of the Connoquenessing and Homewood Formations and the middle sandstone unit of the Mercer are unsually thick. The top of the Mercer is placed at the disconformity at the base of the overlying sandstone member of the Homewood Formation. The base of the Mercer is at the top of the upper sandstone member of the Connoquenessing Formation. Where the upper member of the Connoquenessing is absent, the base of the Mercer has been placed, arbitrarily, 15 feet below the base of the lower limestone bed of the Mercer.

White (1880, p. 134-136) gave three measured sections of the Mercer Formation at Hells Hollow. The base of the Mercer is not given in any of the measured sections, and a driller's log of Mr-1276, indicates that the upper sandstone member of the Connoquenessing intertongues with shales at the type locality of the Mercer. However, the upper member of the Connoquenessing is present half a mile west of Hells Hollow at well Mr-1273, which penetrated 100 feet of continuous sandstone. The middle member of the Connoquenessing is presumably absent at this well. In White's (1880, p. 137) Stranahan Section, which is about half a mile southwest of Hells Hollow, the upper member of the Connoquenessing is 10 feet below the lower limestone bed of the Mercer. The Mercer was not exposed where White's Stranahan section was visited during this investigation; however, the upper member of the Connoquenessing is well exposed, and small pits and the ruins of a kiln shown where the limestone of the Mercer was mined and burned for the Oregon Furnace, which was a short distance to the north. The Oregon Furnace, like the other iron furnaces of the area in the mid-nineteenth century, used charcoal and local iron carbonate ore from the Mercer. The Oregon Furnace was closed down (White, 1880, p. 137) about 1860.

The Mercer Formation is predominantly shale, but it contains as many as three coals and their underclays (the Tionesta, and the upper and lower Mercer coals) and, locally, an upper and lower limestone bed. The upper and lower Mercer coals underlie the upper and lower limestone beds, respectively. The upper coal directly underlies the upper limestone, where it is present, whereas the lower coal may be separated from the lower limestone bed by as much as 20 feet of gray shale. The gray shale may contain a thin coal at the top that is considered to be a "rider vein" or "split" of the lower coal. The Tionesta coal bed has been found only in the Lawrence County part of the Neshannock quadrangle, where it is 10 to 20 feet above the upper limestone bed. In Pulaski and Mahoning Townships it is separated from the Homewood Formation by a 16- to 20-foot interval of shale and planar, very thin-bedded to laminated silty shale and sandy siltstone. This very thin-bedded to laminated shale is here included in the Mercer Formation, and the top of the Mercer is placed at the disconformity at the base of the overlying thin white sandstone that represents the sandstone member of the Homewood.

The upper and lower limestone beds of the Mercer are discontinuous, black, fossiliferous limestones, 0 to 3 feet thick, which weather to medium gray and are typically separated by an interval of 30 feet. The interval between the two limestone beds is predominantly gray shale, but it includes a discontinuous sandstone unit, 0 to 30 feet thick, which is here referred to as the middle sandstone unit of the Mercer. The middle sandstone unit is fine to medium grained in 1- to 2-foot thick planar beds or planar sets of cross strata, and there is a local disconformity at the base of the unit.

The middle sandstone unit is best developed in the same areas where the sandstone members of the Homewood and the Connoquenessing Formations are thick, as in wells La-560, and La-883. (See Section B-B′, Plate 2.)

The Mercer coals are usually slaty and are split locally into two or more beds by thin beds of shale. The greatest thickness recorded during this investigation for any of the Mercer coals was about 3 feet. However, White (1879 and 1880) reports localities where the lower Mercer and Tionesta coals are up to 4 feet thick. The Tionesta coal bed is developed best in the Lawrence County part of the Neshannock quadrangle. It was mined extensively by stripping methods in Pulaski and Mahoning Townships from 1946 to 1960.

The Tionesta coal bed was not being strip mined in the Neshannock quadrangle during 1961. The upper and lower Mercer coals have been mined by underground methods at many places in the Neshannock quadrangle for local domestic use, but only one underground mine was in operation in 1961. It was producing from either the upper Mercer or Tionesta coal along old Pennsylvania State Route 18 about 2 miles north of New Castle. The mine was a one-man operation in which coal was mined for local domestic use.

The Mercer Formation is not well exposed in the Neshannock quadrangle, but it is of considerable stratigraphic importance because it includes the upper and lower limestone beds, which are key stratigraphic marker beds in the Neshannock quadrangle. White (1879 and 1880) gives many measured sections of the Mercer from natural exposures in stream cuts and from areas where the Mercer coals were being mined at the time of his investigation. Many of these sections are no longer exposed.

Natural exposures of the base of the Homewood Formation and the upper and lower limestone and coal beds of the Mercer Formation may be seen in Mercer County at Hells Hollow and in the valley immediately to the south. They may be seen in Lawrence County between Carter and Lake Roads, south of Volant, Pa., and in a tributary entering Neshannock Creek by the Maple Grove Church, 2 miles south of New Wilmington, Pa.

The Homewood Formation, Tionesta coal, upper and lower limestone and coal beds of the Mercer Formation, and the upper part of the Connoquenessing Formation are well exposed in a valley three-quarters of a mile northeast of Parkstown, Pa., between Peanut, Pa. and Hillsville, Pa. opposite the Ambrosia Coal Company Tipple. In a small gully 1 mile north of Peanut, Pa., the middle sandstone unit of the Mercer is well developed, and well preserved marine shells may be collected from a sandy shale bed overlying the upper limestone bed of the Mercer Formation.

Homewood Formation

The name "Upper Homewood" was proposed by White (1878, p. 67) to replace the names "Piedmont" and "Tionesta", which had been applied previously to the uppermost sandstone unit of the conglomerate measures (Pottsville Group) of early reports in western Pennsylvania. In his report on Lawrence County, White (1879) reverted to the use of the term "Tionesta" for this sandstone. In an appended special report on the correlation of the coal measures, in the same volume, the name "Homewood" was substituted for the name "Tionesta" by Lesley (White 1879, p. xxx). The term "Homewood" was used by White in subsequent county reports on the geology of northwestern Pennsylvania.

The exposure of conglomeratic sandstone at Homewood Station, Beaver County, Pa., was designated by White (1878, p. 67) as the type locality of the Homewood, because of the large thickness (155 feet) of sandstone at that locality. White considered that the abnormal thickness of the Homewood at Homewood Station resulted from the extension of the Homewood upward, into the Allegheny Group, above the horizon of the Vanport Limestone. DeWolf (1929, p. 49) considered that the exposures at Homewood Station represented the combined Homewood and Connoquenessing Formations, because "the bed is unusually thick, and the additional thickness seems largely at the base. Furthermore the neighboring sections lend themselves readily to such interpretation."

The exposures at Homewood Station were not restudied during this investigation; however, field evidence in the Neshannock quadrangle reveals that coalescing of sandstone units of different ages is common. The coalescing of the sandstone units is interpreted as the result of sandstone-filled channels that have cut through underlying rocks to a lower sandstone unit.

The major sandstone units of the upper part of the Pottsville Group are lithologically similar to those of the Allegheny Group; they were, presumably, derived from a common source area and deposited in similar environments. Where these sandstone units of the Pottsville and Allegheny coalesce, they cannot be distinguished as separate units by megascopic field criteria, and the scarcity of outcrops generally makes it impossible to delineate the steep sides of the sandstone-filled channels.

In the eastern part of the Neshannock quadrangle, the sandstone units of the Kittanning and Homewood Formations and those of the Homewood and Connoquenessing Formations coalesce, forming locally continuous sequences of sandstone throughout the intervals at Homewood Station discussed by both White (1878, p. 67) and DeWolf (1929, p. 49).

The name "Tionesta" (Homewood) was used to include not only sandstone but sandy shale, shale, and coal by White (1879, p. 53-56). DeWolf (1929, p. 51-52) used the name (Homewood) for the same interval. As defined by White and DeWolf, the Homewood extends from the base of the Tionesta (Homewood) coal up to the top of the sandstone or sandy shale. Leggette (1936, p. 170) included the Tionesta (Homewood) coal and the shales above it in the Mercer Formation. Later investigators placed the upper limit of the Pottsville Group at the base of the Brookville coal or its underclay, thereby including within the Pottsville an unnamed shale unit, 0 to 40 feet thick, which is considered here as the upper member of the Homewood Formation. Concerning the areal variation in the lithology of the Homewood, White (1880, p. 84) stated that in Lawrence County the sandstone graded into sandy shale at many places, but in Mercer County the lithology was consistent.

In this report the Homewood Formation is considered to consist of two members: (1) an upper shale member extending up to the base of the Brookville coal or its underclay, and (2) a lower member composed predominantly of medium-grained sandstone having a disconformity at its base. The thin planar-bedded sandy shales that underlie the disconformity at the base of the lower sandstone member were included by White (1879, p. 54) and DeWolf (1929, p. 48) in the Homewood, but they are included here in the Mercer Formation.

Despite uncertainties concerning the limits of the Homewood at its type locality, and changes in the limits of the Homewood in other localities

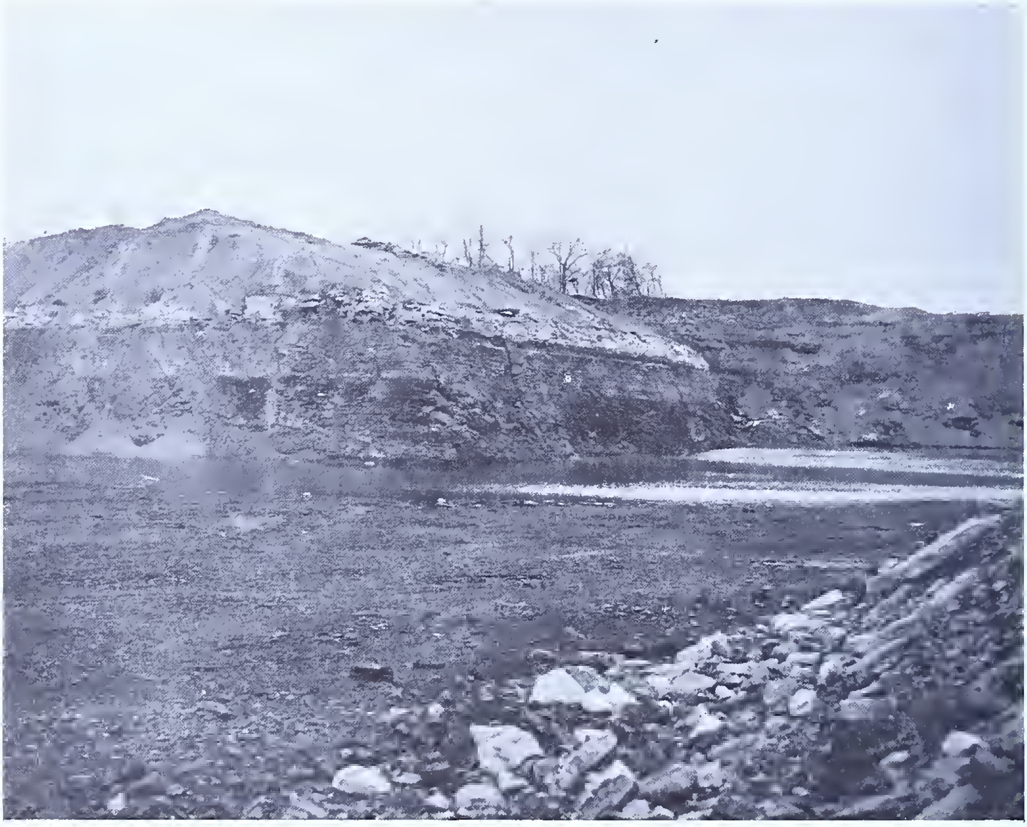

Figure 6. Sandstone member of the Homewood Formation 1 mile northeast of Robinson, Lawrence County, Pa., caps planar bedded shale, silt and thin sandstone beds. Tionesta coal bed is at base of pit, and the Brookville underclay forms much of slope above the Homewood.

by White and subsequent workers, the name "Homewood" has been used since White's (1880) work for the uppermost formal stratigraphic unit of the Pottsville Group in northwest Pennsylvania.

Lower sandstone member.—The lower sandstone member of the Homewood Formation is typically fine- to medium-grained, locally coarse to conglomeratic, light-gray to pale yellowish-orange quartz sandstone, which weathers brownish gray to moderate brown and generally contains carbonaceous trash and impressions of tree trunks. In well-weathered exposures in the uplands, the sandstone is soft, white, and friable; whereas in fresh exposures in narrow ravines, the sandstone is hard and dense, and the intergranular pores are filled with white clay. The sandstone in the lower member is locally planar bedded, but it occurs typically in planar sets of cross-strata 1 to 2 feet thick. Resultant downdip direction of cross-beds, as measured in 30 outcrops in the Neshannock quadrangle, was to the northwest. The thickness of the member ranges from 0 to 60 feet, and the maximum relief on the disconformable surface at the base of the unit is about 50 feet. The lower sandstone member is well developed in the north and eastern parts of the area, where it has not been removed by erosion, but it is generally only 3 to 5 feet thick and locally discontinuous in the southwestern part of the Neshannock quadrangle. (See Fig. 6.) The lower sandstone member could not be mapped continuously throughout the Neshannock quadrangle; so, it is mapped in local areas only.

The lower sandstone member is exposed at a few places in road cuts on the hilltops in the northern part of the area and in ravines in other parts of the area—where it usually forms a break in the slope of the stream floor. Upper and lower boundaries of the Homewood are arbitrarily projected in places where the sandstone of the Homewood is continuous with that of the Connoquenessing Formation or the sandstones of the Allegheny Group.

Upper shale member.—The upper member of the Homewood Formation is typically a light- to medium-gray shale, which is rarely exposed in the Neshannock quadrangle. The member ranges in thickness from 0 to 40 feet, but it is commonly 15 to 20 feet thick in the eastern part of the quadrangle and 6 to 12 feet thick in the southwest part of the quadrangle. The upper shale member is absent as a result of erosion in the northwest part of the Neshannock quadrangle, and it is thin and discontinuous in the northeast part of the area where its position is taken by younger channel-filling sandstone units of the Allegheny Group. The contact between the upper and lower members of the Homewood is rarely exposed. Where it can be seen, in the Neshannock quadrangle, it is generally gradational. The upper boundary of the member is placed at the base of the Brookville coal or its underclay.

Allegheny Group

Clarion Formation

The term "Clarion coal group" was applied by geologists of the First and Second Pennsylvania Geological Surveys to a stratigraphic interval containing shale, sandstone ,limestone, and several economically important coal beds. It was considered by geologists of the Second Survey as the lowest of three coal groups forming the Lower Productive Coal Measures of older reports (Allegheny Group of this report). The Clarion coal group, as shown by White (1878, p. 40-41) extended from the top of the Piedmont (Homewood) Sandstone to the top of the Ferriferous (Vanport) Limestone. The names "Clarion Sandstone" and "Vanport Limestone" have long been applied to distinctive lithologic units within the Clarion coal group, and the names "Brookville", "Clarion" and "Scrubgrass" have been applied to coal beds within the Clarion Formation.

The interval included within the Clarion coal group of older reports was referred to as the Clarion Formation by Ashley (1926, p. 29). After the work of DeWolf (1929), the lower boundary of the Allegheny Group and, hence, the Clarion Formation, was changed from the top of the Homewood Formation to the base of the Brookville coal or its underclay.

The interval here included in the Clarion Formation was described as containing three coals and their underclays in Lawrence County—by White (1879 and 1880), DeWolf (1929), and Leggette (1935)—but only two coals in Mercer County (White, 1880, p. 27) and (Leggette, 1936, p. 180). During this investigation, only two persistent coals were identified in the Clarion Formation in the Neshannock quadrangle. White (1879, p. 169-174) described a Brookville coal and a Clarion coal in separate measured sections at Hettenbaugh Run, in the southeast part of the Neshannock quadrangle, and White (1880, p. 27) showed both the Brookville and the Clarion coals in a compiled section from the same locality. The identification by White of two distinct coals (Brookville and Clarion) at Hettenbaugh Run appears to have been based on variations in the interval between the Scrubgrass coal or the Vanport Limestone and his Brookville or Clarion coal. Compiled well data and exposures in strip pits along Mitchell Road, 2 miles north of New Castle (Section B-B′, Plate 2), suggest strongly that the interval between the Brookville coal and Scrubgrass coal thins in areas where the sandstone members of the Homewood and the Connoquenessing thicken or coalesce; therefore, using intervals below marker beds as the sole criteria for distinguishing coal beds could lead to errors in correlation.

The Clarion Formation, as used in this report, includes the strata lying between the base of the Brookville coal or its underclay and the base of the Vanport Limestone. The Vanport Limestone is excluded from the Clarion because the Vanport is a distinct, mappable, lithologic unit. The Clarion Sandstone of older reports is here referred to as the sandstone member of the Clarion Formation. The Clarion is typically 50 feet thick and, where the sandstone member is not present or is poorly developed, is composed of gray shale (containing nodules of siderite) and two persistent coal beds; namely, the Brookville and the Scrubgrass.

The propriety of using the name "Brookville" for the coal at the base of the Clarion Formation has long been questionable, because the coal at Brookville is believed to be the stratigraphic equivalent of the Mercer coals of Mercer County (Graeber and Foose, 1942, p. 51) and (Ashley, in Moore and others, 1944, p. 681). Despite problems of correlation, the name "Brookville" has been and is commonly used for the lowest coal of the Clarion Formation in northwestern Pennsylvania.

Although the Clarion coal was not recognized in the Neshannock quadrangle during this investigation, it has been recognized in adjoining areas where the bedrock is not largely covered by glacial deposits (DeWolf, 1929, p. 45) and (Richardson, 1936, p. 32).

The coal beds of the Clarion Formation were extensively mined in the Neshannock quadrangle by underground and stripping methods; however, in 1960 there was only one small underground mine producing coal from the Clarion.

The Brookville coal ranges in thickness from 0-5 feet and was the most mined coal of the Clarion Formation in the Neshannock quadrangle. The Scrubgrass coal seldom exceeds 10 inches in thickness in the Neshannock quadrangle and was never mined extensively. The Brookville coal is thickest in the eastern part of the area, where it is also the most discontinuous coal—being cut out by younger channel-fill sandstones in many places.

The sandstone member of the Clarion Formation is not well developed in the Neshannock quadrangle and could not be traced. The sandstone member crops out below the Vanport Limestone on both sides of the Youngstown Road, in Mahoning Township, 5 miles northwest of New Castle, Pa., where 45 feet of the micaceous crossbedded sandstone is exposed; however, the base of the sandstone member is not exposed. Where the Clarion Formation was observed in the Mercer and Stoneboro quadrangles, the base of the sandstone member of the Clarion was disconformable. The sandstone member of the Clarion may be well developed in the areas where the other sandstone units of the Pottsville and Allegheny Groups thicken and coalesce—forming overlapping linear belts of thicker sandstone. In these areas, the well developed sandstone member of the Clarion would be inseparable from sandstone units of the Homewood and Kittanning Formations.

The Clarion Formation is well exposed in a ravine 1 mile east of Hillsville, Pa., and the lower part of the Clarion is exposed in the "high wall" in several strip pits in Mahoning Township, Lawrence County, Pa., and in a ravine in Union Township, 1 mile northeast of Parkstown, where a small underground mine was producing from the Brookville coal in 1960. Complete sections of the Clarion Formation are exposed in ditches on either side of the road to Eastbrook, Pa., 1½ miles east of Coaltown, Pa., and in gullies north of Hettenbaugh Run, 1½ miles east of Eastbrook.

The lower part of the Clarion is exposed 1 mile south of Volant, Pa., in a valley tributary to Neshannock Creek. At this locality, the sandstone unit of the lower member of the Kittanning Formation has cut out the Brookville coal. Exposures of the Clarion Formation are rare in Wilmington, Lackawannock, and East Lackawannock Townships, Mercer County, and the interval in which the Clarion would be expected is occupied generally by sandstone of the Kittanning Formation; however, some of this sandstone may represent the sandstone member of the Clarion Formation.

Vanport Limestone

The name "Vanport Limestone" was first used by White (1878, p. 60) for exposures of limestone at Vanport, Beaver County, Pa. He used it as a synonym for Ferriferous Limestone, the name applied to this unit in reports of the First and Second Pennsylvania Geological Surveys, and the name White continued to use in succeeding reports on the geology of counties in northwest Pennsylvania. After publication of the reports of the Second Geological Survey of Pennsylvania, the name "Vanport" came into common usage in the geologic literature concerning western Pennsylvania, and the name "Ferriferous" ceased to be used as a stratigraphic term.

In this report the Vanport is considered to be a separate formation overlying the Clarion Formation, because it is lithologically distinctive and has long been used as a key horizon for stratigraphic and structural studies in western Pennsylvania.

The Vanport ranges in thickness from 0 to 22 feet in the Neshannock quadrangle. It is fossiliferous, and where it is typically developed it consists of an upper light-gray unit and a lower more siliceous bluish unit 3 to 4 feet thick. An irregular bed of siderite (iron carbonate) locally caps the Vanport and was mined in the mid-19th century as a source for iron ore for local charcoal furnaces.

Weathered surfaces of the Vanport have a characteristic "shriveled" appearance (White, 1879, p. 45, and DeWolf, 1929, p. 45). Variations in the thickness of the Vanport are fairly abrupt; for example, 1 mile northeast of New Castle, Pa., on Graceland Road, 15 feet of Vanport lenses out northward and disappears entirely in less than 500 feet, and its position is taken by fossiliferous dark gray shale.

South of an arcuate line extending southward from the northwest corner of Mahoning Township, Lawrence County, through Parkstown, thence east through Briar Hill and north to Volant, the Vanport maintains its characteristic lithology and is essentially continuous where it has not been removed by recent erosion. (See Fig. 7.) North of the arcuate line, the Vanport is variable in its physical characteristics and is discontinuous. It consists of a single thin bed of black fossiliferous limestone, 0-1 foot thick, in the "high wall" of strip pits north of Mitchell Road. In a strip pit 1½ miles north of Harbor, Pa., it consists of a sequence of black and gray beds of limestone, 0-4 feet thick, showing cone-in-cone structure.

The Vanport has not been observed in that part of the Neshannock quadrangle within Mercer County, although many of the ridges in the northeast part of the Neshannock quadrangle are above the stratigraphic horizon at which the Vanport would normally be expected. Concerning the apparent absence of the Vanport in the area south of Greenfield, Lackawannock Township, White (1880, p. 24) stated, "We must conclude then one of three things; either 1, that the drift is deep on this ridge, or 2, that the interval between the two limestones is here exceptionally large; or 3, that the original deposit of the ferriferous limestone in Mercer County was as irregular in extent and thickness as in Lawrence, Beaver, and Butler Counties."

Exposures are poor in Lackawannock and East Lackawannock Townships, as the bedrock in the uplands is masked by glacial deposits. Bedrock exposures in ravines are predominantly sandstone, and generally the stratigraphic marker beds in shale units of the Pottsville and Allegheny Groups cannot be traced for great distances. Field evidence suggests that the shale units thin and disappear locally where major channel-fill sandstones overlie and underlie them, as shown in Section A-A′, Plate 2. Stratigraphic marker beds of coal and limestone within the shale units appear to drape or arch over areas underlain by unusually thick deposits of sandstone. This draping or arching of marker beds is believed to be the result of differential compaction between areas where shale is predominant and areas where sandstone is predominant.

One mile south of Volant, Pa., the Vanport Limestone is cut out by a northwest-trending channel-fill sandstone of the lower member of the Kittanning Formation. Although the edges of this sandstone are not well defined, field data indicate that the meander belt in which the sandstone-filled channel occurs is about 5 miles wide. In a ravine 1 mile south of Volant, the channel cuts at least 40 to 50 feet below the horizon of the Vanport. Although there is no evidence available as to whether or not the Vanport was deposited in Lackawannock and East Lackawannock Townships, there is positive field evidence of erosion in this area during the time interval in which the overlying Kittanning Formation was being deposited.

The Vanport Limestone has long been of economic importance and is, according to Miller (1934, p. 126) "* * * the most valuable limestone of

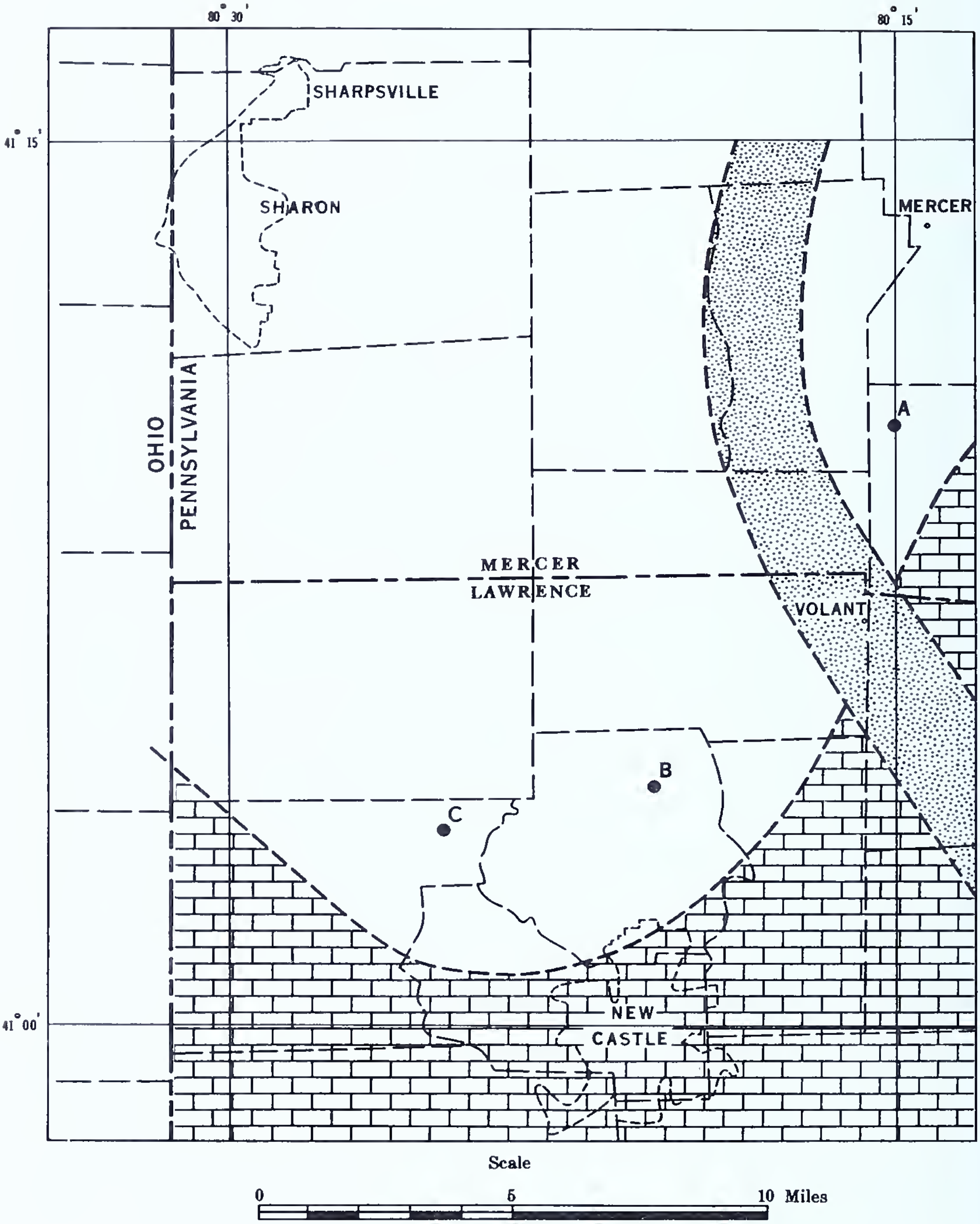

Figure 7. Distribution of the Vanport Limestone, Vanport typically developed in shaded area. In unshaded area the Vanport is thin, discontinuous, and represented by black limestone beds at A and B. At area C limestone shows cone in cone structure. Dotted area indicates channel-fill sandstone of Kittanning age.

the carboniferous strata of the State." Mining has removed all of the Vanport, except its lower layer, from Mahoning Township, Lawrence County, and a large area east of New Castle, in Hickory Township. Miller (1934) gave many detained sections and chemical analyses of the Vanport Limestone. He discussed, also, the companies that mined the Vanport and the utilization of their products. Because the Vanport has been essentially removed from this area, Miller's data are chiefly of historical interest and are not reviewed in this report.

Kittanning Formation

The name "Kittanning" was applied by Rogers (1858, p. 467) to a thin bed of coal at Kittanning, Pa. Roger's Kittanning coal bed, the lower Kittanning coal bed of later reports, was traced into Allegheny, Butler, Beaver, Lawrence, and Mercer Counties, by White (1878, 1879, 1880). The name "Kittanning coal group" was applied to a variable sequence of shale, sandy shale, sandstone, and three beds of coal lying between the top of the Buhrstone Ore (top of the Vanport Limestone) and the top of White's Darlington coal bed. White first applied the name "Darlington" to the uppermost of the three coals included within the Kittanning coal group. According to Lesley (in White 1880, p. 23, and DeWolf 1929, p. 41), White commonly used the name "Darlington" in reference to the middle Kittanning coal of later reports, and, in some instances (White 1879, p. 37-180), used the name "Darlington" uncertainly in reference to the lower Kittanning coal bed.

In his report on the Punxsutawney quadrangle, which is about 65 miles east of the Neshannock quadrangle, Ashley (1926, p. 27) used the name "Kittanning Formation" for the strata between the base of the clay under the lower Kittanning coal and the top of the upper Kittanning coal. The name "Clarion Formation" was applied to the strata between the base of his Kittanning Formation and the base of the Allegheny Group (which is the base of the clay underlying the Brookville coal). By so fixing the lower limits of the Kittanning Formation, Ashley included in his Clarion Formation the lower part of the Kittanning coal group of older reports. Ashley did not recognize the Kittanning Sandstone, as used in older reports, and because the Vanport Limestone was seen at only one point in the Punxsutawney quadrangle, it could not be used for stratigraphic subdivision of Allegheny rocks. The name "Kittanning Sandstone" was applied by White (1878, p. 59) to a locally prominent sandstone unit in the lower part of the Kittanning coal group of older reports.

Most reports dealing with the geology of Lawrence and Mercer Counties follow White's usage of the term "Kittanning Sandstone," although they differ regarding the rank of the unit—depending upon whether the Allegheny was considered a formation or a group. In recent reports on the Pottsville and Allegheny rocks by Williams (1957; 1959; 1960, p. 1293), Williams and Nickelsen (1958), Degens, Williams, and Keith (1958), and Ferm and Williams (1960), the base of the Kittanning Formation has been placed, as defined by Ashley (1926, p. 27), at the base of the clay underlying the lower Kittanning coal.

In this report the Kittanning is considered as a formation extending from the top of the Vanport Limestone to the top of the upper Kittanning coal, and, thus, having the same limits as the Kittanning coal group of older reports. The Kittanning Formation is subdivided into lower, middle, and upper members occupying, respectively, the intervals from the top of the Vanport Limestone to the top of the lower Kittanning coal; the top of the lower Kittanning coal to the top of the middle Kittanning coal; and the top of the middle Kittanning coal to the top of the upper Kittanning coal. The prominent sandstone referred to by White and subsequent workers as the Kittanning Sandstone is referred to in this report as the sandstone unit of the lower member of the Kittanning Formation.

Erosion has removed the upper part of the upper member of the Kittanning in the Neshannock quadrangle. The maximum thickness of the Kittanning Formation in the Neshannock quadrangle is about 120 feet.

The Kittanning Formation is represented principally by shales and sandy shales in the Neshannock quadrangle—except in the northeastern part of the quadrangle, where the sandstone unit of the lower member of the Kittanning fills channels cut locally into strata as old as the Homewood Formation. Except for the sandstone unit of the lower member, the Kittanning does not crop out in natural exposures in the Neshannock quadrangle.

The lower member of the Kittanning caps the high ridges in East Lackawannock and Wilmington Townships, Mercer County and in eastern Wilmington, northeast Hickory, and northern Washington Townships, Lawrence County—where the lower member of the Kittanning is represented chiefly by the channel-fill sandstone unit of the lower member. In central and southern Hickory Township, the channel-fill sandstone unit of the lower member intertongues laterally with shale. As a result, the thickness of the lower member ranges from 10 to 60 feet and averages about 40 feet in southwest Hickory Township where the member is composed predominantly of shale and thin laterally discontinuous beds of sandstone and sandy shale. In Union and Mahoning Townships, Lawrence County, the lower member is represented by 40 to 50 feet of bluish-gray shale. The lower member of the Kittanning has been removed by strip mining in preparation for mining the Vanport Limestone from large areas of Mahoning Township and smaller areas of southern Hickory Township, Lawrence County.

The lower Kittanning coal, where seen in southern Hickory and Mahoning Townships, ranged in thickness from 1½ to 2½ feet. It was reported by strip-mining operators to range in thickness from 0 to 4 feet, which is the range given in older reports. The lower Kittanning coal bed is extremely irregular in its position with respect to the Vanport, and in strip pits there is as much as 40 feet of relief between the highest and lowest elevations of the bed within lateral distances of a few hundred feet.

DeWolf (1929, p. 43) gives a range in thickness of 12 to 36 inches and an average thickness of 24 inches for the lower Kittanning coal in that part of Lawrence County south of the Neshannock quadrangle. He gives a range in thickness of 4 to 10 feet for the fire clay underlying the lower Kittanning coal. The maximum thickness of the clay below the lower Kittanning coal in the Neshannock quadrangle is not known but is believed to be about 10 feet. White (1879, p. 38) reported the clay to be more than 10 feet thick about 1 mile east of New Castle, Pa. During this investigation, the clay underlying the lower Kittanning coal was seen in the Neshannock quadrangle at one locality in southern Hickory Township, about 1 mile east of New Castle, where it ranges in thickness from 3 to 8 feet.

The underclay is mined by the Fenati Brick Company. Both the lower Kittanning coal and its underclay have been mined in southern Mahoning Township, Lawrence County, but these strata have been essentially removed by strip mining in preparation for mining the Vanport Limestone. In the Neshannock quadrangle, the lower Kittanning coal has been mined by underground methods in Union, Neshannock, Hickory, and Washington Townships, Lawrence County; and strip mined in Hickory and Washington Townships, Lawrence County.

In the Neshannock quadrangle, the middle member of the Kittanning is restricted to small areas in southern Mahoning and Union Townships, east central Neshannock Township, southern and eastern Hickory Township, and western Scott and Washington Townships, Lawrence County.

The middle member of the Kittanning was exposed in high walls of strip pits in southern Mahoning Township in 1960. Just south of the Neshannock quadrangle, half a mile south of Peanut, Mahoning Township, the middle member was 40 feet thick. It consisted of a lower 20-foot unit of gray shale, a middle 12-foot unit of interbedded fine-grained sandstone and shale, and an upper 6-foot unit of gray shale and underclay capped by 4 to 12 inches of middle Kittanning coal. About half a mile west of this section, the middle member was 50 feet thick.

In Hickory Township, the middle member of the Kittanning was exposed in the high wall of two strip pits in 1960. One pit was three-quarters of a mile southeast of Community Church, the other was 1½ miles northeast of Eastbrook. In both places the member consisted principally of 30 to 40 feet of shale, but it was sandy at the top and contained beds of sandstone in some places.

The middle Kittanning coal was reported to have been penetrated during coal-test drilling on the hilltops west and north of Neshannock Church, about 2 miles east of New Castle, in southern Hickory Township. A well drilled at Laurel School (La-615), about 1½ miles east of the Neshannock quadrangle, penetrated a fire clay (overlain by shale) in the approximate stratigraphic position of the middle Kittanning coal. The shale reported to overlie both the middle Kittanning coal near the Neshannock Church and the fire clay at Laurel School is the only known erosional remnant of the upper member of the Kittanning in the Neshannock quadrangle.

Unconsolidated Deposits

Pleistocene Deposits

Pleistocene deposits of unconsolidated clay, silt, sand, and gravel cover the bedrock throughout the Neshannock quadrangle, except for exposures in the stream valleys, in man-made excavations, and in small isolated patches on the ridge tops. Some of these Pleistocene deposits include pebbles and boulders of igneous and metamorphic rocks that have been transported from a source in Canada, but the majority of material in the glacial deposits was probably derived locally. Glacial striae in the Neshannock quadrangle are oriented S. 20°-30° E., indicating the main direction of glacial flow.

The distribution and character of the Pleistocene deposits were mapped and described by Shepps and others (1959), the preglacial drainage was shown by Leverette (1934, p. 93), and the buried valleys were given special attention by Leggette (1936, p. 15-27). Only the broader aspects of the Pleistocene deposits are discussed in this report.

According to Shepps and others (1959, p. 8), the continental ice sheets advanced into northwest Pennsylvania at least seven times; two of these advances were in Illinoian time and five were in Wisconsin time. Of these seven advances, only three are definitely known to have entered the area of the Neshannock quadrangle; two of these in Illinoian time and one in Wisconsin time entirely covered the area. The deposits associated with the widespread advance of the continental ice sheet during Wisconsin time have been assigned to the Cary stade and correlated with the Kent Moraine by Shepps and others (1959, p. 31).

Pleistocene deposits include material deposited directly beneath or in front of the ice sheets as ground or end moraines. These deposits are called till and are composed of a heterogeneous accumulation of clay, silt, sand, pebbles, and boulders that lack sorting and stratification. They include also deposits from melt water from the ice sheet. These deposits are known as eskers, kames, kame terraces, and valley trains and are composed of fairly well-sorted, stratified beds of silt, sand, and gravel.

Lake deposits are believed to be present in some of the large valleys, but the thickness and extent of these deposits is not well defined. The existence of lake deposits is postulated from drillers' logs of wells (drilled in the buried valleys) that show gray clay or quicksand but no gravel or boulders. In addition, information from drill cores provided by the Corps of Engineers, U. S. Army, from other buried valleys in the region, shows laminated or varved clay in the upper part of the buried valleys.

The distribution of Pleistocene deposits in the Neshannock area is shown by Shepps and others (1959, Pl. 1). Information from well logs shows the uplands to be covered with 10 to 20 feet of till. The upper part is generally weathered yellowish or brownish, whereas the unweathered till is characteristically bluish gray. Buried valleys traversing the uplands are generally filled with till, and although available well logs do not record beds of gravel at the base of these valleys, such deposits may be present.

Glacio-fluvial deposits of silt, sand, and gravel—in the form of kames and kame terraces—cover the flanks of the large stream valleys and much of the valley of Lackawannock Creek. Also, a prominent esker can be seen in the Greenfield 7½ minute quadrangle, north of Indian Run.

The valleys of the Mahoning and Shenango Rivers and Neshannock Creek are filled with predominantly fine-grained sand, silt, and clay to depths ranging from 100 feet to more than 200 feet. Information concerning these valley-fill deposits in the Neshannock quadrangle is from drillers' logs of water wells. Logs of wells in the buried valleys typically record quicksand or blue clay; beds of coarse sand and gravel are seldom reported.

Some of the fine sand and clay is believed to have been deposited in lakes that occupied the major valleys after the last retreat of the continental ice sheet. However, these valley-fill deposits are complex and may contain material deposited before and during the glacial advances as well as during the interglacial stages.

Successive advances of the continental ice sheet probably re-excavated those valleys parallel to the general direction of glacial movement and filled preglacial and interglacial valleys that were aligned at a high angle to the direction of glacial movement. If this is true, highly permeable fluvial and glacio-fluvial gravels could be expected beneath till and other glacial deposits in those buried valleys that intersect the general direction of glacial movement at a high angle. Another possible location for coarse permeable material would be at the junctions of the major stream valleys of Pleistocene time and their tributaries. At these junctions, some of the tributaries would have discharged into post-glacial lakes and formed deltas containing coarse sediments. Modern stream valleys may provide an indication of where to prospect for buried deltas in post glacial lakes.

Locating and defining the occurrence of such permeable deposits would be an important step in the development of large quantities of ground water from the Pleistocene deposits in the Neshannock quadrangle.

Before the advance of ice across the area, the major through-flowing stream in the Neshannock quadrangle was the Old Beaver River. According to Leverett (1934, p. 92-93) this stream discharged northward through the valley of the present Shenango River, between New Castle and Sharon, and thence to the St. Lawrence River valley by way of the Grand River.

The advancing ice sheet dammed the northward-flowing major streams and formed lakes that were forced to overflow low cols and discharge southward. The end result of the repeated advances of ice across the area, and the deposition of glacial deposits by each advance, was the complete reversal of the major drainage of the area.

Minor stream drainage prior to glaciation and during interglacial stages is not well understood, because many of the valleys—particularly those parallel to the direction of glacial movement—were deepened and altered by the advancing ice sheets. Also, melt water draining from the glaciers deepened some old valleys and excavated new valleys. The minor stream drainage was probably altered by each advance and retreat of the ice sheets.

Recent Deposits

In Recent time, alluvium—composed of clay, silt, sand, and gravel—has been deposited in the valleys of the larger creeks and rivers by streams in flood stage. These Recent deposits are generally thin and overlie thicker valley-fill deposits of Pleistocene age.

In times of flood, streams increase their velocity, deepen their channels, and carry a large load of sediment. As the flood subsides, and the velocity of the stream decreases, the sediment is deposited. Migration of the stream channel, back and forth across a flood plain, results in the deposition of discontinuous beds of both coarse and fine sediment. Information on the total thickness of the alluvium and the vertical changes in lithology is not available for the Neshannock quadrangle; however, data from nearby areas suggests a maximum thickness of about 20 feet.

STRUCTURE

Mississippian and Pennsylvanian strata in the Neshannock quadrangle dip gently to the south and southeast at the rate of approximately 15 feet per mile. This regional dip is broken in the northwest corner of the Neshannock quadrangle, where the Cussewago Sandstone dips approximately 50 feet per mile to the southeast.

Many local irregularities and reversals of dip are superimposed upon the regional dip. They are interpreted as draping of beds of silt, shale, and coal over thick channel-fill sandstone units of the Pottsville Group, as a result of differential compaction.

The identification and tracing of key horizons for use in making a structural contour map of the Neshannock quadrangle presents several problems. The sandstone and shale units of the Pottsville and Allegheny Groups cannot be used as a base for structural contouring because exposed sandstone units characteristically have an erosional base and their upper parts intertongue laterally with shale. In the southern part of the area, where the Vanport Limestone is well developed, the Vanport serves as an excellent horizon for structural contouring. Unfortunately, the Vanport is missing throughout much of the quadrangle as a result of erosion. In the northeast part of the quadrangle, where the ridges are high enough for the Vanport to be present, channel-fill sandstone of Kittanning age occupies the interval where the Vanport should be.

The limestone beds of the Mercer Formation are useful key horizons in some areas. They are not completely satisfactory, because there are two such beds separated by up to 30 feet of shale. Both limestone beds are discontinuous and have been eroded away in the northwest part of the Neshannock quadrangle and in areas where the sandstone units of the Pottsville reach maximum development. In addition, these limestone beds occur in similar sequences of strata and are difficult to identify unless both beds are present in one exposure. In spite of the foregoing difficulties, the limestone beds of the Mercer are the best available control for structural interpretation of exposed strata in the Neshannock quadrangle. The Cussewago Sandstone is the best subsurface horizon for structural interpretation; however, because of the scarcity of information from wells drilled to the Cussewago, this formation could be used only to define the regional dip.

Jointing

Jointing is easily identified on rocks exposed in the Neshannock quadrangle. Measurements of the strike of joints made during this investigation indicate two prominent joint systems. One system trends N. 40°-45° E. and the other trends N. 40° W.

Valleys of minor streams that flow on bedrock characteristically follow the strike of the prominent joints, and it is assumed that jointing largely controlled the position of preglacial valleys. The joint system that trends N. 40° W. probably facilitated the erosion of valleys by the continental ice sheet, during the Pleistocene Epoch.

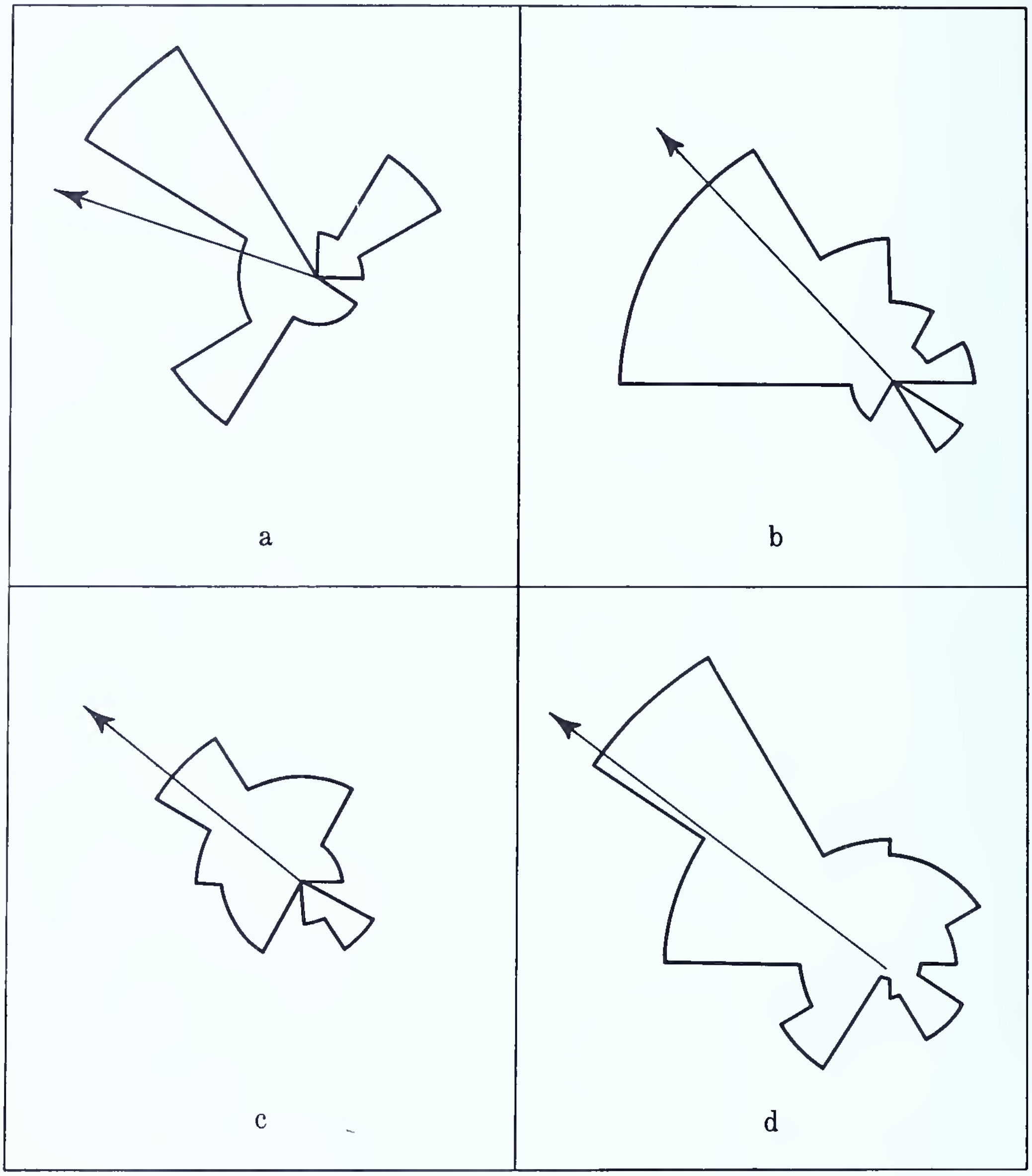

Figure 8. Diagrams showing the direction of dip of crossbeds in (a) the lower member of the Connoquenessing Formation at 26 localities; (b) the upper member of the Connoquenessing at 30 localities; (c) the sandstone member of the Homewood Formation at 23 localities; (d) composite of all dip directions for the Pottsville Group. Arrows show the vector means of direction of dip of the crossbeds.

Sedimentary

Structure in rocks of the Allegheny and Pottsville Groups, caused by the draping of silt, shale and coal over thick sandstone units, is believed to give up to 50 feet of relief. However, the absence of good marker beds in the areas of linear belts of overlapping sandstone units makes it impossible to determine the relief accurately.

The dip directions of crossbedding in fluvial sandstone beds indicate the direction of local flow in the streams depositing the sandstone. Because streams (and deeper channels within streams) meander, many observations on the dip of crossbeds are required in order to define major directions of stream transport and source area. Ideally, these observations should have a random areal distribution. Measurements of dip directions of crossbeds in the Neshannock quadrangle are from a comparatively small geographic area and cannot be considered random samples, unless it is assumed that the outcrops of bedrock are randomly distributed. Such an assumption may be questionable for an area where there are few exposures of bedrock.

Measurements of the dip direction of crossbedding in the sandstone units of the Allegheny and Pottsville Groups (see Fig. 8) show that the predominant direction of dip is northwestward.

Williams (1959, p. 4) reported a southwest dip direction for crossbeds in the Pottsville Group south of the Neshannock quadrangle. According to Williams, "the Pottsville sandstones have a southwesterly crossbedding direction; whereas the middle Allegheny sandstones (Kittanning) have a north northwesterly direction." The few measurements of the dip direction of crossbeds in the sandstones unit of the lower member of the Kittanning Formation that were made during this investigation showed that the dip was northwestward.

MINERAL PRODUCTS AND FUELS

Mineral resources of the Neshannock quadrangle include (other than oil and gas) limestone, coal, fire clay, refractory sand, sand and gravel, and building stone. Current utilization of these resources is shown in Table 1. Some oil has been produced from the Hundred-foot sand, near Volant, and from the Berea Sand, in the Bessemer pool, in the southwest corner of the quadrangle. In the northeast corner of the quadrangle some gas is still produced from the Hundred-foot sand.

In 1961 there was little oil and gas exploration in the quadrangle, and the only production was principally oil from the Volant field, most of which is east of Volant and outside the area covered by this report.

Coal was found in the Neshannock quadrangle shortly after the area was settled. Eavenson (1952, p. 225), reports that coal was found near

Table 1.—Mineral products (except oil and gas) of the Neshannock quadrangle during 1959.*

Company	*Nearest City*	*Commodity*	*Uses*
	LAWRENCE COUNTY		
Michigan Limestone Division, U. S. Steel	Hillsville	Limestone	Blast furnace flux, cement, roadstone.
Cambria Slag Company (Lawrence Limestone Quarry)	New Castle	Limestone	Concrete, roadstone.
New Castle Lime & Stone Company	Mahoning Township	Limestone	Concrete, roadstone, agriculture, coal dust.
Fenatie Brick Company, Inc.	New Castle	Clay	Building brick.
Keystone Loam & Clay Company	Edinburg	Clay	Refractories.
Mahoning Valley Sand Company	New Castle	Sand and gravel	Building and paving sand and gravel, railroad ballast gravel, and miscellaneous gravel.
Superior Sand & Supply Company	New Castle	Sand and gravel	Paving sand and gravel.
Elwood Stone Company	New Castle	Sandstone	Refractory purposes.
Ambrosia Coal and Construction Company	Edinburg	Bituminous coal	Strip mine.
Corry Excavating & Mining Company	Volant	Bituminous coal	Strip mine.
	MERCER COUNTY		
Welty M. Smeltzer	Volant	Sandstone	Building stone.
Seger Sand and Gravel	West Middlesex	Sand and gravel	Building sand and gravel.
Seidle Sand and Gravel Company	Mercer	Sand and gravel	Building and paving sand and gravel.
W. B. Taylor	Sharon	Sand and gravel	Miscellaneous sand and gravel.

* Information provided by the U. S. Bureau of Mines, Pittsburgh Office of Mineral Resources.

Sharon—probably as early as 1810—and that actual mining began about 1835. Coal was mined for local consumption until the opening of the Beaver and Erie Canal in 1844. From 1844 until about 1959 coal was mined from the area for commercial and local domestic use.

Recent coal production has come mostly from strip mines in the Brookville coal and the Tionesta coal. In the past, underground mining produced considerable tonnage of coal from the lower Kittanning, Brookville, Tionesta, upper and lower Mercer, Quakertown, and Sharon coals. Small-to-moderate reserves of coal are present in all of these beds except the Sharon, which, for all practical purposes, was mined out before 1900. In 1961 only two small underground mines were in operation, both of which were very small—producing coal for local domestic consumption only.

The Vanport Limestone has been removed by quarrying operations from several square miles of land along the southern boundary of the quadrangle. It is used for cement, blast furnace flux, roadstone, and agricultural lime. The Vanport was not being mined in the Neshannock quadrangle in 1961, although it was being mined southwest of the quadrangle—not far from Hillsville, Pa. Deposits of the Vanport Limestone remaining within the area are either of small areal extent or deeply buried.

Fire clay from beneath the lower Kittanning coal is occasionally mined in the southeast part of the quadrangle for making building bricks. Sand and gravel are mined from eskers, kames, and valley train deposits at many places in the quadrangle. Sandstone from the Connoquenessing Formation is quarried 3 miles north of New Castle for refractory purposes. A small quantity of sandstone from the Connoquenessing is quarried near Volant for ornamental building stone. In the mid-nineteenth century, small deposits of siderite and bog iron ore, associated with the Vanport Limestone and limestone beds of the Mercer Formation, were mined for use in charcoal furnaces.

GROUND WATER

General Features

Ground water is the subsurface water in the zone of saturation—the zone in which all the rock voids are filled with water under pressure greater than atmospheric. The water table is the upper surface of this zone. The water table occurs at a relatively shallow depth beneath the ground surface throughout most of the Neshannock quadrangle.

In the Neshannock quadrangle the zone of saturation may be divided generally into two parts. The upper part, which occupies the first few hundred feet below the water table, contains circulating fresh water. The lower part contains highly saline connate brine, which is, presumably, static. The two fluids meet in a direct contact, which cuts across a number of geologic units, and constitutes the limiting stream surface of the fresh-water system.

There are no completely impervious rocks within the fresh-water zone in the Neshannock quadrangle. The shales are extremely low in permeability, but they are saturated with moving fresh water. The entire fresh-water system in the Neshannock quadrangle may, therefore, be treated as a single unit. The dynamics of the fresh-water system can be described in terms of a single three-dimensional flow net in which the lines of flow and surfaces of equal hydraulic head are controlled both by topography and by differences in the hydraulic properties of the various rock units. The upper limit of this flow net is the water table, and the lower limit is the brine contact.

In the following section the hydraulic properties of the various rock types in the Neshannock quadrangle are summarized briefly. Ground-water movement, well performance, and water quality—in relation to a three-dimensional flow net—are discussed in succeeding sections.

Hydraulic Properties of the Rocks

A general knowledge of the hydraulic properties of the various geologic units is essential to an understanding of the ground-water system as a whole. The discussion of hydraulic properties presented here is basically qualitative, since very little exact quantitative data have been accumulated. However, some information is available on the orders of magnitude of the hydraulic coefficients of the sandstones, and this information has considerable importance in connection with estimating the yields of wells. Definitions of the significant hydraulic coefficients are given in the following paragraphs.

Specific capacity.—The specific capacity of a well is defined as the ratio of its discharge to the corresponding drawdown in its water level. Specific capacity is in general a function of the properties of the aquifer, the radius and efficiency of the well, and the duration of pumping; it is expressed generally in gallons per minute per foot.

Permeability.—The coefficient of permeability, K, of a porous medium is defined as the fluid discharge rate maintained through a unit cross sectional area of the medium by a unit hydraulic gradient. It is a measure of the capacity of the medium to transmit fluid. In this report, the fluid under consideration is fresh water, and the permeability refers to the ability of the medium to transmit water. If the hydraulic gradient is expressed in dimensionless form, such as feet of hydraulic head per foot of flow distance, permeability may be expressed in such units as gallons per day per square foot.

Transmissibility.—The coefficient of transmissibility, T, of an aquifer is defined as the coefficient of permeability of the aquifer multiplied by the thickness of the aquifer. It may be expressed in such units as gallons per day per foot. Experience shows that the permeability and thickness of an aquifer may differ considerably from one place to another; so, the transmissibility may differ also from place to place.

Storage coefficient.—The storage coefficient, S, of an aquifer is defined as the volume of water the aquifer releases from storage per unit surface area of the aquifer per unit decrease in the component of head normal to that surface. If volume, area, and head are expressed in consistent units, storage coefficient is a dimensionless quantity. It is a measure of the aquifer's ability to store or retain water that is forced into it under hydraulic pressure and to release this water upon removal of the pressure.

The sandstones of the Pennsylvanian and Mississippian Systems in the Neshannock quadrangle are generally much higher in both lateral and vertical permeability than the shales of these systems. Drilling experience indicates that the majority of wells in the quadrangle show very low yields where they penetrate only shale and larger yields where they penetrate sandstone. This behavior can be explained only on the basis of higher lateral permeabilities in the sandstones. Normally, beds having low lateral permeability also have low vertical permeability. In the Neshannock area this is borne out by a certain amount of independent evidence suggesting that the shales of the section are low in vertical permeability. For example, the variations in hydraulic head in the vertical direction within a given sandstone bed are extremely small; on the other hand, the vertical head difference across shale beds—that is, the head difference observed between two sandstone beds that are separated by a shale bed—is commonly quite large.

Permeability of both primary and secondary origin occurs in the Pottsville and Mississippian sediments, but there is not sufficient evidence at present to indicate which form is predominant. Since the sandstones are generally higher in permeability, however, it would seem either that primary permeability predominates, or that secondary permeability tends to develop more extensively in the sandstones than in the shales. The shale permeability seems to be high in a few places, because some wells yield large amounts of water from shale. In these places, the permeability is almost certainly of secondary origin; however, such wells are the exception, rather than the rule, in the Neshannock quadrangle.

The coals and limestones of the Pottsville Group constitute only a small part of the group, and very little information on their hydraulic characteristics in the Neshannock quadrangle or elsewhere is available.

No wells in the Neshannock quadrangle are known to obtain water from limestone or coal; therefore, these beds probably have low permeabilities.

The sand and gravel of Pleistocene age are much more permeable than the silt and clay. The gravels are usually much more permeable than the sandstones of Pottsville and Mississippian age.

The quantitative evaluation of the hydraulic coefficients of a porous medium generally requires carefully controlled laboratory or field testing. Unfortunately, only one such test was made during the investigation of the Neshannock quadrangle; this was a pumping test on well Mr-978, which taps the Cussewago Sandstone at West Middlesex, Pa.

In order to compensate for the lack of testing within the Neshannock quadrangle, test results from other areas, providing data on the aquifers in question, were utilized. The general applicability of these test results to the Neshannock area was checked by the following method: Theoretical relations between the specific capacity of a typical well penetrating each sandstone and the thickness of that sandstone in the vicinity of the well were developed by using the results of the tests. Ratios of specific capacity to sandstone thickness, for wells within the quadrangle, were then computed from data supplied by drillers and well owners, and the results of these calculations were compared with the theoretically predicted ratios. Where the comparison was favorable, it was concluded that the hydraulic coefficients as given by the test results were at least of the proper order of magnitude for the Neshannock quadrangle. In attempting to analyze the Connoquenessing Formation, for which the results of the comparison were somewhat inadequate, an effort was made to explain the apparent discrepancies on the basis of geologic conditions and to estimate the actual range in hydraulic properties of the Connoquenessing in the Neshannock quadrangle. In analyzing the Mississippian sandstones above the Berea, for which no quantitative test results were available, an effort was made to estimate ranges for the hydraulic coefficients on the basis of the specific-capacity and thickness data alone.

The figures obtained through these methods must obviously be treated as approximations, having only order of magnitude significance. This is especially true since the results of the quantitative testing indicate that the individual sandstones may differ in permeability from place to place.

Most of the quantitative testing was in the form of pumping tests of wells; these tests yielded figures for storage coefficients and lateral transmissibilities. The coefficients of transmissibility were converted to coefficients of permeability, because the thickness of most of the sandstones differs from place to place. The conversion required only division of the transmissibility figures by the thicknesses of sandstone in the test wells.

As indicated above, the quantitative data indicates that the permeability of the individual sandstones differ from place to place. These differences can be caused by variations in grain size, sorting, cementation, and the development of fracturing. The information available is not extensive enough to establish geographical patterns of permeability variation in any of the sandstones. The only conclusion that can be stated regarding the permeability of a given sandstone at a given point in the quadrangle, is that it will probably fall somewhere within the indicated range.

In the following pages, the sandstones are discussed individually in regard to their permeability, thickness, and transmissibility, and the apparent ranges in each of these variables are presented for each sandstone. The approximate thicknesses of the sandstones in many localities can be inferred from the information on general geology and stratigraphy presented earlier in this report. Where this is possible, the permeability range of the sandstone may be combined with the thickness of sandstone at the point in question, to determine the transmissibility range at that point. This local transmissibility range will generally be much narrower than the transmissibility range given for the sandstone in the area as a whole.

Following the discussions of permeability, thickness, and transmissibility, a general discussion of storage coefficient in the Pottsville and Mississippian sediments is presented. The use of these parameters in estimating well yields is outlined in the section of well performance.

Pumping tests were made on four wells tapping the sandstone member of the Homewood Formation in areas adjacent to the Neshannock quadrangle. The coefficients of permeability determined from these tests ranged from 9 gpd per ft^2 to 35 gpd per ft^2. The specific-capacity and aquifer-thickness data from wells within the quadrangle indicate that the permeability of this sandstone within the quadrangle varies in this general range. The thickness of the sandstone member within the quadrangle ranges from 20 to 40 feet. Combining the permeability and thickness ranges gives a possible transmissibility range of about 200 gpd per ft to 1,400 gpd per ft for the sandstone member of the Homewood.

The Connoquenessing Formation is about 130 feet thick, and may contain both sandstone and shale. The ratio of sandstone thickness to shale thickness within the interval differs from place to place. In some places the formation is almost entirely shale, and in others it is almost entirely sandstone.

The permeability of the sandstone in the Connoquenessing apparently also differs widely from place to place. Permeabilities of 10 gpd per ft^2 and 100 gpd per ft^2 were obtained from two pumping tests in areas adjacent to the quadrangle. The specific-capacity and aquifer-thickness data from wells within the quadrangle suggest strongly that the spread in permeability is much wider than these pumping tests indicate, and actually extends from about 5 gpd per ft^2 to about 300 gpd per ft^2.

The variation from sandstone to shale within the Connoquenessing involves transition through intermediate lithologic types such as sandy shale, siltstone, and shaly sandstone. The various intervals reported as sandstone in the specific-capacity data may actually represent a wide range of sedimentary classifications between clean sandstone and sandy shale. Thus, the only safe conclusion that can be drawn from the data is that transmissibility in the Connoquenessing may range from near 0 gpd per ft, where the sandstone members are thin and shaly, to about 30,000 gpd per ft where they are thick and clean. The probability of encountering the highest transmissibilities in any one well is low, because such transmissibilities require both high permeability and great sandstone thickness. In some places, however, these conditions are apparently met, and the Connoquenessing is capable of supplying relatively high yields.

No pumping-test results are available for wells producing from aquifers of Mississippian age above the Berea Sandstone. The principal aquifers in this interval are the Shenango Formation and the sandstones of the Cuyahoga Group; these sandstones include the Sharpsville, which can be traced in the subsurface in the southern part of the Neshannock area, and many local sandstones. The total thickness of sandstone of Mississippian age, above the Berea, apparently ranges from 20 to 100 feet. The data on specific-capacities of wells and sandstone thickness suggest that the permeabilities of sandstones in this interval generally range from 5 to 50 gpd per ft^2. If this is true, transmissibilities ranging from 100 to 5000 gpd per ft could be present in the Neshannock quadrangle. The probability of encountering the highest transmissibilities, for which both permeability and thickness must be maximum, is relatively low.

The Berea Sandstone is not an important aquifer in the Neshannock quadrangle. In the southern part of the quadrangle, where the sandstone is relatively thick, it is saturated with brine. In the northern part of the quadrangle it contains fresh water but becomes progressively thinner and finer grained and eventually disappears altogether. No pumping-test data are available for wells producing from the Berea; however, oil has been produced from this sandstone elsewhere in the "Appalachian basin," and some quantitative work has been done on the unit by the oil industry. Permeability figures have been published in the range from 1 to 500 millidarcies, or, approximately, from 0 to 10 gpd per ft^2. The small amount of available data on the specific capacity and aquifer thickness of the Berea indicate that its permeability is probably in this range in the Neshannock quadrangle. The thickness of the Berea in the region of fresh-water saturation may range from 0 to 30 feet, and its transmissibility should, therefore, fall somewhere between 0 and 300 gpd per ft.

Analysis of the pumping test at West Middlesex shows a permeability of 25 gpd per ft^2 for the Cussewago Sandstone. No other permeability figures are available for this sandstone; however, the data on specific capacity and aquifer thickness suggest that this figure is of the proper order of magnitude, and that any variation in permeability is probably between limits of 10 and 40 gpd per ft^2.

The Cussewago is saturated with brine in the southern part of the quadrangle. It contains fresh water in the northern part of the quadrangle and ranges in thickness from about 30 feet to about 60 feet. Thus, the transmissibility of the Cussewago, in the region of fresh-water saturation, probably ranges from 300 to 2400 gpd per ft.

The various pumping tests in the Homewood and Connoquenessing Formations, and the test in the Cussewago Sandstone, all give storage coefficients that seem unusually high for consolidated artesian aquifers. The coefficients range from 10^{-4} to 10^{-2}, whereas the storage coefficient for a consolidated artesian aquifer is normally between 10^{-6} and 10^{-3}. The determination of storage coefficient by pumping test analysis is highly sensitive to experimental error, and this may account in part for the abnormal results. It is unlikely, however, that all of the test results are in error to such an extent, and it seems safe to conclude that the storage coefficients are generally high.

In the discussion of ground-water movement, it is shown that the vertical flow of water through shale beds is an important factor in the regional movement of ground water in the Neshannock quadrangle. It seems reasonable, therefore, to suppose that vertical leakage through the confining shales supplies an appreciable part of the water that is apparently withdrawn from storage in the sandstones during well discharge. The validity of this interpretation cannot be fully established by the small amount of data available. However, the preliminary indications are that the storage coefficients of sandstones in the Pottsville Group and sandstones of Mississippian age are unusually high and are actually apparent storage coefficients, reflecting the increased vertical flow of water into the sandstones from the confining shales in the vicinity of a discharging well. The fact that the figures may actually be only apparent storage coefficients does not affect appreciably their utility in predicting well performance. In general, with the data available, it is possible only to estimate the orders of magnitude of well yields. It should be permissible then, to assume a storage coefficient of 10^{-3} for the sandstones of Pennsylvanian and Mississippian age in the Neshannock quadrangle.

THE GROUND-WATER SYSTEM IN THE NESHANNOCK QUADRANGLE

General principles of ground-water flow

Hydraulic head, as used in this report, is defined by the equation

$$h = Z + \frac{P}{\rho g} \qquad (1)$$

Where h is the hydraulic head at a given point in a fluid system, Z is the elevation of the point above an arbitrary datum, P is the hydraulic pressure at the point, ρ is the density of the fluid, and g is the acceleration due to gravity.

The term $\frac{P}{\rho g}$ gives the height of a static column of the fluid that can be supported above the point in question, so that the hydraulic head is the elevation above datum of the upper surface of such a column. As defined in equation (1), hydraulic head is a measure of the potential energy carried by a unit weight of the fluid at a given point in the flow system. Losses in head from one point to another indicate the energy consumed in overcoming frictional resistance to flow between the points. The kinetic energy of flow is usually negligible in ground-water systems, and it is, therefore, unnecessary to include a velocity term in equation (1).

In ground-water systems, hydraulic head may be measured as the elevation to which water will rise in a tightly cased well that penetrates to the point in question and is open to no other point below the water table. Where it is unnecessary to consider variations of head with time, or where the distribution of hydraulic head at a particular instant of time is of interest, surfaces of equal hydraulic head may be used to describe the variations of head in three dimensions. A surface of equal hydraulic head is an imaginary surface within the earth, points on which have the same value of hydraulic head. A family of such surfaces can serve to illustrate the head distribution in three dimensions.

The fluid pressure exerted upon points on the water table is essentially the atmospheric pressure. Because this pressure is exerted upon all parts of the ground-water system, it need not be considered in the calculations, and the term $\frac{P}{\rho g}$ for points on the water table may be taken as zero. Thus the head at a point on the water table is simply the elevation of the point above datum. Contour lines on the water table are, therefore, lines of equal head that mark the intersections of the three-dimensional surfaces of equal head with the water table.

Movement of ground water in the steady state is governed by Darcy's law, which may be expressed as

$$\frac{Q}{A} = -K_x \frac{\delta h}{\delta x} \tag{2}$$

in which Q is the volumetric fluid-discharge rate through a cross-sectional area A in a porous medium, when the head gradient normal to A is $\frac{\delta h}{\delta x}$, and the permeability of the medium in this direction is K_x. The negative sign indicates that the flow is in the direction of decreasing head. It follows from Darcy's law that in a homogeneous and isotropic porous medium, lines of flow are perpendicular to the surfaces of equal head, and a detailed quantitative description of the flow system can be derived from head data. The situation is more complex in heterogeneous or anisotropic media, but even in these media qualitative representations of the flow pattern can usually be obtained from head data.

The circulation of fresh ground water is one stage of the hydrologic cycle. It constitutes a segment of the discharge system through which water that falls as precipitation eventually returns to the sea. A fraction of the precipitation falling on an area infiltrates to the saturated zone and then flows, according to Darcy's law, either directly to the sea through an aquifer system or, more commonly, into a stream and through the stream system to the sea.

The earth is generally a heterogeneous and anisotropic porous framework for ground-water flow. The flow system will tend to adjust to a pattern of minimum resistance through this framework by crossing beds of low permeability in the shortest possible paths and then moving relatively long distances through the beds of high permeability. In an area such as the Neshannock quadrangle, in which shales of low permeability alternate with more permeable sandstones in a nearly horizontal section, and where the region is cut by well-developed stream systems, ground water will tend to flow almost vertically across the shales and will move laterally through the sandstones—toward the stream valleys. The flow will, thus, tend to be undirectional within a given sandstone or shale unit, and the effects of internal anistrophy in these units should be minor. Flowlines and surfaces of equal head will be roughly perpendicular within a given bed, and both will be refracted sharply at lithologic contacts.

In seeking the pattern of minimum resistance, the ground-water system may develop several superposed paths of flow. For example, direct circulation into the local streams may occur through the uppermost aquifers, while the deeper aquifers carry flow (maintained largely by vertical leakage from the upper aquifers) from a large area toward the major stream valleys.

In addition to their ability to transmit water according to Darcy's law, saturated earth materials possess the ability to absorb additional water into storage. In a water-table aquifer, ground-water storage can be accounted for by changes in the level of saturation. The mechanism of storage in confined aquifers is not fully understood at the present time; however, as the hydraulic head on a confined aquifer is increased, water is apparently forced into storage within it, as though the pore spaces were expanded and the fluid compressed by the increase in pressure. The quantity of water taken into storage is observed to be directly proportional to the applied head increase, the constant of proportionality for a given aquifer being the storage coefficient (S) defined in the preceding section.

If the head is increasing with time at a given point in a ground-water system, inflow to the segment of aquifer in the vicinity of that point exceeds outflow, and water is being taken into storage; if head is falling, outflow exceeds inflow and is being released from storage in the vicinity of the point. The essential characteristic of a ground-water system at equilibrium, in which the head distribution is unchanging with time, is that inflow and outflow are in balance throughout the system.

Because of the erratic nature of recharge by precipitation, ground-water systems are seldom truly in equilibrium, as the hydraulic head must increase during periods of recharge and decline during periods of discharge. Over a long period of time, however, the average natural outflow of a ground-water system tends to balance the average recharge, and the head variations tend to be fluctuations about a mean.

In areas where the lower limit of the ground-water flow system is a direct fluid contact between fresh ground water and a connate brine of higher density, some information on the fresh-water system can be derived from the position and attitude of this contact. A relatively simple analysis of the situation can be given if diffusion is assumed negligible and the brine is assumed to be static; in most cases these assumptions appear to be good approximations to the existing conditions.

It can be shown that the fresh water adjacent to the contact can flow, even though the brine is static. This flow of fresh water will parallel the contact—in other words, the limiting streamlines of the fresh-water system will lie along the contact. The contact will rise in the direction of fresh-water flow, attaining a maximum elevation under channels of ground-water discharge, and a maximum depth under major ground-water divides. Because the flow along the contact represents the deepest segment of the fresh-water system, it will generally be the most regional in nature; the position and attitude of the brine contact is, thus, usually related to the major streams and the major divide areas, and may be relatively unaffected by more local ground-water circulation in the shallow aquifers.

Ground-water flow in the Neshannock quadrangle

The Neshannock quadrangle, as indicated previously, has a relatively uniform upland surface that is cut by a network of stream valleys, many of which are filled to a considerable depth with unconsolidated rocks of Pleistocene age. The stream valleys form natural avenues of local discharge for ground water, which may then either find its way into the streams and leave the region as surface-water discharge or move out of the region through the unconsolidated sediments filling the valleys as ground-water discharge. The upland regions intercept most of the precipitation falling on the quadrangle, because they make up the bulk of its area; therefore, they are the most important areas of recharge for the ground-water system. The general pattern of ground-water flow is downward and outward from the high regions, and upward and inward toward the stream valleys. The circulation from the uplands to the valleys, however, is superposed throughout most of the quadrangle upon a more regional circulation from areas north of the quadrangle to the Shenango and Mahoning River valleys.

Plate 3 shows an idealized geologic and hydrologic cross section, along a diagonal line extending from the southwest corner to the northeast corner of the quadrangle. The hydrologic features represented on the section include the water table, the contact between fresh water and connate brine, lines of equal hydraulic head, and general directions of flow. The lines of equal head represent the traces, on the vertical plane of the section, of the three-dimensional surfaces of equal head; similarly, the lines representing the water table and brine contact represent the traces of these surfaces on the vertical plane of the section. The flow net shown on the cross section is only a first approximation, as control was limited, and the various features represented may fluctuate seasonally. The section is intended to illustrate the general ground-water pattern, rather than to give exact quantitative data.

The ground-water flow tends to cross shales and other low-permeability units vertically, and to move laterally toward the valleys through the sandstones. The surfaces of equal head are, thus, nearly horizontal in the shales, are refracted sharply at sandstone-shale contacts, are almost vertical in the sandstones, and are elongate parallel to the valleys. Plate 3 shows that the highest surfaces of equal head close beneath the topographic highs within the quadrangle. It shows also that some of the lower surfaces close beneath the smaller streams, others extend out of the quadrangle to the north or northeast, and the lowest surfaces close beneath the major stream valleys or intersect the brine contact.

The flow patterns corresponding to this potential distribution are both local and regional in character. A part of the precipitation infiltrating to the ground-water system in the uplands flows through the Pennsylvanian rocks, in a relatively local pattern, to the adjacent streams; the remainder percolates downward into the Mississippian sandstones, adding to the regional movement of ground water. Everywhere north of the Mahoning River valley this deep, regional flow seems to be to the south or southwest. The indications are that this regional discharge is one segment of a large-scale flow pattern, similar in form to the more local flow, but directed from the major topographic divides to the large river valleys and continually added to by vertical leakage. If this is true, the southward regional flow probably originates in the divide areas bounding the Mahoning-Shenango Rivers drainage system to the north and east of the Neshannock quadrangle. Thus, the source of most of the fresh ground water in the Neshannock quadrangle is the precipitation falling directly on the quadrangle and on topographically higher areas to the north and east.

The Mahoning River valley and, to some extent, the Shenango River valley form discharge channels for the regional flow. The Mahoning River valley is probably the limit of the southward flow, and the regional flow south of the Mahoning River valley is probably northerly, toward the valley, as indicated on the cross section. The Shenango and Mahoning River valleys may discharge only a part of the southward flow—the rest of it flowing on to the Ohio River valley. There is very little data on the hydraulic head in the deep aquifers south of the Mahoning River, or on the position of the brine contact in that area; therefore, more precise definition of the regional flow is not possible.

The position of the brine contact in the Neshannock quadrangle is known only approximately, but it has been established that it rises to the south or southwest and cuts across the Cussewago and Berea Sandstones in the central part of the quadrangle. This indicates clearly that the position of the contact is controlled by the regional flow of ground water to the south or southwest.

If the origin of this regional flow is in the divide areas bounding the Mahoning-Shenango Rivers drainage system, the brine contact must continue to decline for 20 or 30 miles north and northeast of the quadrangle, reaching its maximum depths in the divide regions. Similarly, if the Shenango and Mahoning Rivers discharge all of the regional flow from the north, the contact must reverse itself and begin declining south of the Mahoning River valley. If only a part of the deep circulation from the north is discharged by the Shenango and Mahoning Rivers, the contact must rise to a crest beneath the Ohio River valley.

The assumption that the brine is static seems to be acceptable in the Neshannock quadrangle, because accumulations of oil and gas have been found associated with the brine in the Cussewago and Berea Sandstones in the southern part of the quadrangle, and such accumulations normally require static reservoir conditions. The brine is very high in ionic concentrations, and may contain as much as 180,000 ppm dissolved solids.

Conventionally, artesian aquifers are defined as confined aquifers in which the hydraulic head is higher than the upper surface of the aquifer. The cross section (Plate 3) shows that throughout most of the Neshannock quadrangle all sandstones below the uppermost shale satisfy this definition. However, these artesian (confined) zones are linked to the overlying water table (unconfined) zones, and to one another, in a continuous hydraulic system. This qualification should be kept in mind whenever the terms "artesian" or "unconfined" are applied to aquifers in this region.

Beneath the upland areas of the quadrangle, the hydraulic head generally decreases with depth, the decreases occurring mostly across the beds of shale. Beneath the small valleys in the uplands, head at first increases and then decreases, so that there is a division of ground-water flow beneath these valleys. In the unconsolidated sediments of the Shenango and Mahoning River valleys, the hydraulic head increases continuously with depth, except in a few localities where pumping has lowered the head in the deeper zones. The increases of head in these valleys seem to be considerably less than the decreases observed in the upland areas, indicating the flow of water through the consolidated rock uses more energy than the flow through the unconsolidated rocks.

As mentioned in the discussion of geology, available information indicates that the unconsolidated sediments of the Shenango and Mahoning River valleys, and of the larger upland valleys as well, are predominantly fine silt and clay. If this is so, the greatest percentage of the ground water entering these larger valleys probably flows into the streams and discharges as surface water—rather than as stream underflow in the unconsolidated sediments.

WELL PERFORMANCE

From a practical or economic point of view, there are three topics that must be considered in discussing the performance of a water well: (1) The depth to water prior to pumping, (2) the specific capacity of the well and its variation with duration of pumping, and (3) the quality of the water produced by the well. In this section, the first two of these topics will be considered for wells in the Neshannock quadrangle.

Economic significance of static level and specific capacity

Specific capacity and the water level prior to pumping determine the cost of pumping from a well. The power needed to pump water to a height m, at a discharge rate q, is given by the product mq. If the height to which the water must be lifted varies with time, while the discharge rate remains constant, the power required to supply the discharge must vary with time. In a water well, the height to which the water must be pumped is composed of two segments: (1) the distance from the land surface to the water level prior to pumping, and (2) the drawdown, or distance from the water level prior to pumping to the water level during pumping. The first segment is normally constant; the second is determined by the specific capacity of the well, and normally it increases as the time of pumping increases. If u is used to represent the distance from tank intake to water level prior to pumping, and s(t) is used to represent the time varying drawdown, the instantaneous power output required to supply a discharge q to a storage tank is

$$P(t) = q\,[u + s(t)]. \qquad (3)$$

The cost of operating the pump for a given length of time depends upon this power output, the length of time involved, and the efficiency of the pumping system, which normally decreases as the depth to water increases. Equipment costs, as well as operating costs, are influenced by these factors, since the pump should be powerful enough to maintain the required discharge from the deepest pumping level that may be encountered.

Factors controlling specific capacity and water level in the Neshannock quadrangle

Water wells in consolidated rock in the Neshannock quadrangle yield chiefly from the sandstones of the section. The shales, except where fractured, are too low in permeability to contribute significantly to well yields. The shales are capable of transmitting relatively high discharges vertically, as part of the regional ground water circulation, but this is due to their large cross-sectional areas of flow, which compensate for their low permeability. In the radial flow of water to a well, the cylindrical area through which the flow must pass diminishes continually toward the well and is smallest at the well. The shale permeabilities are generally too low to permit a large discharge through the walls of the well.

The water level in a well is determined by the vertical distribution of hydraulic head in the rocks through which the well is drilled and by the transmissibility and storage coefficients of these rocks. If the well is to be drilled at a point beneath which the head has some constant value (H) throughout the depth interval to be penetrated, the water level in the well will stand at height H above the datum. If, however, the well is to be drilled at a point beneath which variations in head occur at different depths, the water level in the well will represent some balance between the various hydraulic heads present before drilling.

Examination of the cross section of Plate 3 shows that vertical variations in head exist at almost all points in the Neshannock quadrangle. An open borehole in the consolidated formations acts essentially as a path of low resistance, through which the vertical flow of ground water can proceed more easily than through the shales. When a well is completed through more than one sandstone, a new flow pattern is set up in the vicinity of the well; water moves radially toward the borehole in the sandstones of higher head, flows vertically through the borehole, and moves radially away from the borehole in the sandstones of lower head.

In the upland areas, head decreases as the depth increases in the fresh-water zone. The water level of a well drops as it is deepened into each new sandstone, and downward internal discharge prevails throughout the borehole. In the smaller stream valleys, head may first increase and then decrease with depth, as indicated on the hydrologic cross section. If a well in one of these valleys is extended into successive sandstones the water level may rise at first and then drop as the lower sandstones are penetrated. In the major stream valleys, the head generally increases downward through the unconsolidated sediments; these increases tend to be small, and the rises in water level that occur as a well is deepened in the valley sediments will usually be small.

Specific capacity, as stated earlier, is the yield per foot of drawdown of a well. If a graph is plotted showing discharge on the ordinate and drawdown on the abscissa, both corresponding to a specified duration of pumping, specific capacity is the slope of this graph, $\Delta Q/\Delta s$. Jacob (1950) has shown that after a short period of discharge the specific capacity of a well penetrating a single aquifer is given by

$$\frac{\Delta Q}{\Delta s} = \frac{1}{\frac{2.30}{4\pi T}\log\frac{2.25Tt}{r_w{}^2S} + CQ^2} \tag{4}$$

where T is the transmissibility of the aquifer
t is the time since the start of pumping
r_w is the radius of the well
S is the storage coefficient

and C is the entrance loss coefficient of the well, which may have a value on the order of 0.01 ft per gpm of discharge. Equation 4 shows that specific capacity normally decreases logarithmically as the time of pumping increases. It is derived assuming that the rate of discharge does not vary with time; that the aquifer is infinite in extent, is homogeneous and isotropic, is nowhere open to recharge or other discharge, and that head is uniform throughout the aquifer prior to pumping.

Though these conditions are not fully satisfied for the various permeable zones in the Neshannock quadrangle or elsewhere, equation 4 usually holds as an approximate expression for the specific capacity of a well penetrating a single permeable zone and operating intermittently. The permeable zone will generally be areally extensive when compared to the area of influence of such a well. The head variations present originally within the permeable zone are gradual in nature; so, within the area of influence of a well that is operated intermittently, the head can be considered essentially uniform prior to pumping. The permeable zone probably receives a large amount of vertical recharge from the confining beds as the well is pumped; however, if the storage coefficient is considered to include a factor describing this vertical recharge, the expression given by Jacob is still useful as an approximate formula for the specific capacity of the well.

The maximum specific capacity that can be expected from a well tapping a given sandstone in the Neshannock quadrangle can be estimated by applying equation 4 and using a storage coefficient of 10^{-3} and the maximum transmissibility value given for that sandstone in the section entitled "Hydraulic properties of the rocks." The minimum specific capacity that can be expected from the well may be estimated in a similar way, using the minimum transmissibility given for the sandstone. It should be permissible to neglect entrance losses in such calculations—that is, to assume $C = 0$—since the results are intended only as estimates.

The use of equation 4 as an expression for specific capacity should not be taken to mean that the discharges of wells in this area represent unreplenished withdrawals from storage. During pumping, withdrawals from storage in the permeable zones or in the confining beds can be an important factor in maintaining the discharge rate; hence, an expression of the form of equation 4 can often serve as a useful approximation for specific capacity. Most of the wells in the area pump intermittently, and since each horizon is part of a continuous hydrologic system, which is heavily recharged by precipitation, withdrawals from storage in an individual bed are generally replenished during rest periods between pumping. On a regional scale, general increases in ground-water utilization tend to result in a new regional equilibrium, rather than in prolonged withdrawals from storage. In this new equilibrium the natural discharge through the stream valleys is reduced by an amount equal to the increases in utilization.

In the discussion of hydraulic properties, it was indicated that fracturing may be responsible for some of the zones of higher permeability in the consolidated rocks of the area. Also, small isolated fractures can be important in relation to the specific capacity of a well. If a well passes through such a fracture, in a bed whose overall permeability is of reasonable magnitude, the effect of the fracture will be to reduce the entrance losses connected with that zone and, thus, to increase its yield per foot of drawdown. A further effect of this type of fracturing may be an alteration of the geometry of radial flow normally present around a well. This, in turn, will eliminate some of the high head losses due to the rapid decrease in flow area near the well under conditions of normal radial flow. In the Neshannock quadrangle, neighboring wells that penetrate the same section sometimes differ somewhat in specific capacity. The most reasonable explanation for this is that one of the wells intercepts an isolated fracture in one of the permeable zones, and the other does not. Local fracturing may cause a domestic well in shale to be successful if the fractures are large or numerous enough to compensate for the low primary permeability of the shale.

It can be shown (Bennett and Patten, 1960) that the specific capacity of a well increases as each new permeable zone is penetrated, and that the increase is approximately equal to the specific capacity of a well tapping the new permeable zone alone. Thus, the increase in specific capacity that will result from penetration of a new aquifer can be predicted approximately by equation 4, using the transmissibility and storage coefficient of the aquifer in question.

The effect of deepening a well in the upland areas into another sandstone is to increase the term u of equation 3 and to decrease the term s(t). In order to predict whether the net effect of well deepening will be an increase or decrease in pumping costs, accurate information on the transmissibility coefficients, storage coefficients, and original hydraulic heads of the various aquifers is necessary. The data available for these variables in the Neshannock quadrangle are not sufficiently accurate to permit successful prediction of this sort.

During the construction of industrial or municipal wells in the upland areas of the Neshannock quadrangle, therefore, it may be advisable to run pumping tests following the penetration of each permeable zone, in order to determine the optimum well depth. For domestic wells, it would be a good policy to run a brief pumping or bailer test after the penetration of the first sandstone. If this test indicates that the well can supply the necessary yield, and that the water is of suitable quality, no further drilling is necessary. Extending the well into deeper horizons may result in higher pumping and equipment costs.

The following section shows that extending a well into deeper aquifers may sometimes be desirable in order to obtain water of a suitable quality. For such wells, pumping costs may be of secondary importance.

The problem of declines of water levels as wells are drilled deeper is not significant in the major stream valleys—as indicated previously, water levels in wells can be expected to rise slightly as wells in these valleys are deepened. The uppermost rocks in major valleys are predominantly fine-grained lacustrine clays, and in many places there may be no more than one sand or gravel of high permeability in the entire section of unconsolidated rocks. The problems of multiaquifer wells, therefore, are not likely to be as important in the valleys as in the upland regions.

The Cussewago Sandstone has been used extensively in the Shenango valley, in the northern part of the quadrangle. In a few localities the head in this aquifer has been lowered by sustained pumping; in these localities, water levels may decline in new wells if they are drilled through the unconsolidated rocks and into this sandstone.

QUALITY OF WATER

General theory

The chemical quality of the ground water in the Neshannock quadrangle is discussed here in relation to knowledge of the geology and ground-water movement in the area, because the chemical character of the ground water at a given point in the area is strongly affected by processes that act on the water as it moves through the earth toward that point. Therefore, thorough study of the chemical quality of ground water in an area such as the Neshannock quadrangle requires detailed analyses of water samples taken from many parts of the area. The aquifer from which the sample was taken must be determined, and the position or role of that aquifer in the flow net of the area must be understood.

During this investigation, only a few samples that provided the necessary control could be obtained. Most of the data that was obtained, however, fits a certain pattern and supports a reasonably clear interpretation. This interpretation is presented here, together with some discussion of its practical consequences. Because of the small amount of experimental data, the interpretations and conclusions presented here should be treated as hypotheses, rather than as established theory. If additional evidence (accumulated as the ground-water supplies of the region are further developed) seems to support the hypotheses proposed in this section, they may be treated with greater confidence. These hypotheses may very well be established as valid for certain parts of the area, and not for others.

In the field investigation of water quality in the Neshannock quadrangle, all water samples from deep aquifers in the upland areas were obtained from wells that had been cased and sealed through the upper aquifers. The samples representing shallow aquifers, in the upland areas, were taken from shallow wells or from deep wells in which downward internal circulation was present, so that the water in the upper part of the borehole was identical to that in the uppermost aquifer. All chemical analyses were made by the Quality of Water Branch of the U. S. Geological Survey.

Water samples from the shallow aquifers in the upland areas were high in calcium, magnesium, iron, bicarbonate, and sulfate. Calcium ranged from 50 to 100 ppm, magnesium from 10 to 40 ppm, iron from 0.40 to 7.5 ppm, bicarbonate from 190 to 470 ppm, and sulfate from 15 to 70 ppm. A general decrease in each of these ionic concentrations except bicarbonate was observed in the samples from the deep aquifers.

In the samples from the deep aquifers, calcium ranged from 3.0 to 22 ppm, magnesium from 2 to 8 ppm, iron from 0.02 to 1.4 ppm, and sulfate from 0.0 to 8.0 ppm. Bicarbonate, which was higher in these samples, ranged from 430 to 800 ppm. Sodium, which was negligible in the shallow aquifers, ranged from 150 to 500 ppm, and chloride ranged from 8 to 350 ppm.

When wells producing from the deep aquifers are pumped, hydrogen-sulfide gas is frequently observed bubbling out of the water. In the aquifer the hydrogen-sulfide gas is dissolved under pressure. When the water is brought to the surface the hydrogen sulfide pressure is lowered, and the hydrogen sulfide gas bubbles out of solution and is detected easily by its characteristic odor.

Reference to the flow net of Plate 3 and to the discussion of ground-water movement indicates that the water in the deep aquifers was at one time in the shallow aquifers. Thus, it would seem that the differences in ionic content between the water of the deep and shallow aquifers are due to processes that have acted upon the water as it moved downward through the geologic section. The water in the shallow zones, moreover, entered the ground-water system as essentially ion-free precipitation. Its ionic content must, therefore, be the result of solution processes in the soil and uppermost sediments.

The humid climate and abundant vegetation of the Neshannock quadrangle have helped to create soils that are generally high in carbon dioxide, which is produced by the decomposition and oxidation of organic matter. Precipitation filtering through these soils quickly acquires an acid character, owing to the solution of carbon dioxide. This carbon dioxide greatly increases the ability of the water to attack calcium and magnesium carbonates, which are plentiful in most of the unconsolidated sediments of the quadrangle; the reactions that are believed to occur are as follows:

(1) $H_2O + CO_2 \rightarrow H_2CO_3$
(2) $CaCO_3 + H_2CO_3 \rightarrow Ca^{++} + 2HCO_3^-$
(3) $MgCO_3 + H_2CO_3 \rightarrow Mg^{++} + 2HCO_3^-$

Reaction 1 occurs as the water passes through the soil. Reactions 2 and 3 occur as the water percolates through unconsolidated sediments below the soil zone. By the time the water has reached bedrock, at depths of 10 to 50 feet, considerable amounts of calcium, magnesium, and bicarbonate have presumably been taken into solution. When the ground water passes through the unconsolidated sediments, or the uppermost layers of shale and coal, sulfide minerals are attacked, and the sulfur is oxidized. In this way, sulfate ions (SO_4^{--}) are added to the solution. Iron compounds may also be attacked and yield ferrous ions (Fe^{++}) to solution. In many places these processes are probably combined in the solution of iron sulfide, which is abundant in the shales of the region. The reactions might take the following general form:

(4) $2H_2O + 2FeS_2 + 7O_2 \rightarrow 2Fe^{++} + 4SO_4^{=} + 4H^+$

In this way the solution and oxidation of sulfur will produce a weak sulfuric acid, which may further increase the ability of the ground water to dissolve certain minerals.

Whether or not the reactions follow the forms suggested above, the concentrations of calcium, magnesium, iron, and sulfate seem to reach sizable proportions in the uppermost saturated zones beneath the highlands. The remaining question, therefore, concerns the processes that alter the ionic content of the water as it continues downward into the lower aquifers. By way of review, the changes that must be accounted for are a reduction in the concentrations of calcium, magnesium, iron, and sulfate, an increase in the concentrations of bicarbonate, chloride, and sodium, and the appearance of dissolved hydrogen sulfide gas.

The decrease in calcium and magnesium content, and the corresponding increase in sodium concentrations in the shales of the section are suggestive of the ion-exchange process. This process is common in shales. The decrease in iron may also be due to ion-exchange processes, or it may be caused by bacterial action. The increase in bicarbonate can be attributed to the continued solution of calcium and magnesium bicarbonates, and the subsequent exchange of the calcium and magnesium for sodium.

The increase in the chloride content of the ground water may be due to continued additional chloride ions dissolving as the water moves downward. The increase in chloride, and sodium, may be due to small-scale mixing and diffusion between the circulating meteoric water and the more connate brines in regions where the ground-water flow extends into the sediments occupied by these brines.

The removal of sulfate from solution and the appearance of dissolved hydrogen sulfide are probably the result of the same process, or sequence of processes. For example, bacteria and carbon or hydrocarbon may cause the reduction of sulfate, producing hydrogen sulfide and the bicarbonate ion, which then take the place of the original sulfate ion in solution.

If the hypotheses outlined above are correct, the ionic content of water in the valley sediments should change with depth. The flow net in Plate 3 indicates that some flow enters the valleys by moving upward from deep sandstones. The water in the lower part of the unconsolidated sediments in the valleys should, therefore, be similar in composition to the water in these deep sandstones; that is, it should be high in sodium and low in calcium, magnesium, and iron. The flow net shows also that some flow enters the valleys more or less laterally through higher consolidated sediments. The water following this path may still contain appreciable quantities of calcium, magnesium, and iron. In some places, these concentrations may be enriched by the infiltration of precipitation that has fallen directly on the valley area and accumulated calcium and magnesium according to the reaction 1-3. Significant concentrations of these minerals may occur, therefore, in the upper part of the unconsolidated valley sediments. A few analyses of water samples from deep valley sediments have been made, and the results are similar to those obtained for the deep consolidated aquifers. No analyses of samples from shallow valley sediments were available to the authors; however, the reports of well owners and drillers indicate that in many places these zones contain water that is high in iron and hardness.

High chloride content had been reported in water from the deeper unconsolidated sediments in the Mahoning and lower Shenango River valleys. This may possibly be the result of mixing and diffusion between the circulating meteoric water and the more connate brines, which probably occupy the consolidated rocks underlying the valley floors.

Application of theory

The hypotheses concerning ground-water quality outlined in the preceding paragraphs contain some interesting practical implications. These practical implications must be considered tentative for any specfic location until additional investigation either affirm or disprove the underlying hypotheses. The hypotheses concerning ground-water quality are pertinent to the development of ground-water supplies, since the quality of the water obtained from wells can be improved by drilling the wells deeper.

Many wells that tap the shallow aquifers yield water that is high in calcium, magnesium and iron, compared to the water from the deeper aquifers, but the concentrations of these ions are still within tolerable limits. Such wells generally need not be drilled deeper.

Where the hardness and iron content of the water produced from shallow aquifers are beyond tolerable limits, there is good reason to drill the wells deeper. Information available at the time this report was written does not justify a definite statement concerning the advisability of deepening wells throughout the Neshannock quadrangle, but it does indicate that at many locations water of more suitable quality may be obtained by drilling deeper. The water from the deep aquifers is generally softer than water from the shallow aquifers (because sodium has replaced calcium and magnesium in solution), and it is generally lower in iron content. This superior water quality at greater depth is apparently due to the fact that the shales of the geologic section act as a natural softening agent—accomplishing the same result as a commercial softening apparatus.

Several factors should be considered before any well is deepened to obtain water of better quality. All available sources of information on local geology should be consulted first, to determine whether favorable geologic conditions are present; that is, whether or not a second sandstone is within reasonable drilling depth, and whether or not it is separated from the upper aquifer by a significant thickness of shale. Both conditions should be met if conditions are to be presumed favorable.

Wells in the upland areas must generally be cased and sealed through the upper aquifer in order to get water of satisfactory quality from the lower aquifer. If the upper aquifer is not sealed off, downward internal flow will occur in the well during the periods of rest between pumping, because the hydraulic head in the upper aquifer exceeds that in the lower aquifer. Water from the upper aquifer will, thus, invade the lower aquifer and displace the native water of the lower aquifer from the vicinity of the well. As the well is pumped, the best situation that can be hoped for is that the lower aquifer will yield to the well at a much higher rate than the upper aquifer. Even in this situation, the yield of the well will consist of water native to the upper aquifer until the water that has invaded the lower aquifer in the preceding rest interval has been pumped out. In situations where both upper and lower aquifers yield similar amounts of water, or where the lower aquifer fails to yield at all—and simply decreases its rate of thieving during pumping—casing and sealing of the upper aquifer is even more important. The expense of casing and sealing the well should, therefore, be weighed in any consideration of whether to deepen the well in order to improve quality, because there is little chance of obtaining an improved supply unless this is done.

Another factor that must be considered when a well is drilled is that once the upper aquifer has been cased off, the water level in the well will be that of the lower aquifer. As such, it will probably be considerably lower than the water level of the upper aquifer. As demonstrated in the discussion of well performance, this factor can add significantly to the size and cost of the original pumping installation and to the cost of the pump operation.

Still another factor, as noted previously, is that in many places the water of the lower aquifers contains some dissolved hydrogen sulfide gas. Although hydrogen sulfide does not produce troublesome effects of the sort caused by excessive hardness or iron content, it does affect the taste and odor of the water. Individuals who find this effect of H_2S undesirable will probably want to deal with hardness of the water or high iron content by some means other than deepening of the well.

Many uncertainties or risks are involved in any attempt to obtain water of improved quality by deepening a well in the upland regions of the Neshannock quadrangle. In consideration of these drawbacks and uncertainties, many users may choose to rely on commercial softening equipment (where softening is necessary) rather than to invest in deepening and casing their well. Nevertheless, many wells have been deepened in the Neshannock quadrangle and have obtained an improved water supply.

There should generally be less trouble with the hardness and high iron content of water from the valleys than that of water from the highland regions. Shallow zones of poor-quality water are present in the valleys, but it is often possible to drill and case through these zones to obtain water of improved quality in lower sediments. The prevailing direction of ground-water movement is upward, so that the difficulties outlined in connection with the well-deepening process in the highlands are not significant in the valleys. Deepening a well in the valley may produce a decrease in pumping costs, as well as an improvement in water quality.

Hydrogen sulfide has been noticed in water from many of the deeper valley wells; however, there is some evidence to indicate that in the shallow and intermediate zones, decreasing hydrogen sulfide pressure allows some or all of the gas to escape from solution.

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Table 2.—Record of representative wells

Well number and location: See p. xx for description of well numbering system.
Method of construction: Dr, drilled; Du, dug.
Total depth: Reported.
Depth to bottom of casing: Reported.
Aquifer: Qd, Quaternary deposits, predominantly Pleistocene glacial outwash deposits; ℙkl, lower member of Kittanning Formation; ℙv, Vanport Limestone; ℙcn, Clarion Formation; ℙh, Homewood Formation; ℙm, Mercer Formation; ℙco, Connoquenessing Formation, undifferentiated; ℙcol, Connoquenessing Formation, lower member; ℙcou, Connoquenessing Formation, upper member; ℙs, Sharon Formation; Mh, Hempfield Shale; Ms, Shenango Formation; Mm, Meadville Shale; Msh, Sharpsville Sandstone; Mo, Orangeville Shale; Mb, Berea Sandstone; Mc, Cussewago Sandstone.
Aquifer composition: G, gravel; S, sand; Ss, sandstone; Ls, limestone; Sh, shale, and slate of well drillers.
Static water level, depth below land surface: Reported, if no date of measurement is given.
Yield: Reported.
Use: A, abandoned; D, domestic; I, industrial; O, observation; Ps, public supply.
Remarks: Ca, chemical analysis in Table 3; Dd, drawndown during bailer test.

Well number	Location number	Owner	Driller	Date completed	Altitude above sea level (feet)	Method of construction	Diameter of casing (inches)	Total depth (feet)	Depth to bottom of casing (feet)	Aquifer		Static water level		Yield (gpm)	Use	Remarks
										Name	Composition	Date measured	Depth below land surface (feet)			
LAWRENCE COUNTY																
La- 443	E2d-3626				960	Dr		638	36			4-30-56	Flowing			Flowing, abandoned oil or gas test well
461	E2d-4012	Neshannock Township Elementary School	Book & Proch	1956	1193	Dr	8	305	109	ℙco	Ss		200	70	Ps	Ca
536	E2c-2208	J. T. Phillis	Hisey Drilling Company	1957	1100+	Dr	6	70	15	ℙco	Ss Sh		40	9	D	
538	E2c-1703	Dieter	do.	1957	1100+	Dr	6	94	44	ℙco	Ss		50	10	D	
541	E2d-7456	H. M. Moon	U. S. Dean	1957	1235	Dr	6	51	38	ℙkl	Ss Sh	6- 7-57	6.38		D	Ca
545	E2c-6653	Walter Mills	Book & Proch	1957	870	Dr	6	47	20	Ms	Ss Sh		20		D	
546	E2c 8232	Thomas Phenecie	Dittmer and Sons	1957	910	Dr	6	88	43	Mh	Sh		36	16	D	
560	E2d-4013	Neshannock Township High School	Book & Proch	1957	1190	Dr		306		ℙco	Ss		208	55	Ps	Ca
563	E2d-3662	Harry McCreary	do.	1957	1220	Dr	6	49	36	ℙkl	Ss		12	40	D	
564	E2c-6207	Merle L. Cailer	Slaven	1957	1030	Dr	6		26	ℙco			25	10	D	

ℙ is symbol for Pennsylvanian.

Table 2.—Record of wells (continued)

Well number	Location number	Owner	Driller	Date completed	Altitude above sea level (feet)	Method of construction	Diameter of casing (inches)	Total depth (feet)	Depth to bottom of casing (feet)	Aquifer		Static water level		Yield (gpm)	Use	Remarks
										Name	Composition	Date measured	Depth below land surface (feet)			
							LAWRENCE COUNTY—Continued									
La- 565	E2c-3036	C. R. Riethmiller	Dittmer and Sons	1957	1040	Dr	6	64	24	ℙco	Ss	7-10-57	23.74		D	
566	E2c-8257	Grant Smith, Jr.	do.	1957	1120	Dr	6	55	37	ℙcn	Sh		11			
571	E2c-2102	R. Carder	Hisey Drilling Company	1957	1120	Dr	6	53	8	ℙco	Ss Sh		2	10	D	Dd. 50 ft.
573	E2d-4209	Lewis	Book & Proch	1957	1140	Dr	7	137	55	ℙm	Sh		65		D	
579	E2c-0603	Anthony Gigliotto	Dittmer	1957	980	Dr	6	82	32	ℙco	Sh Ss, Sh		40	8	D	Dd. 5 ft.
600	E2d-5555	Wilbur Downing	Elmer Book	1957	1040	Dr	5	85	20	ℙco	Ss	3-57	35	20	D	
601	E2d-4117	W. D. Siebanoller	do.	1957	1220	Dr	5	105	19	ℙh	Ss	4-22-57	20.81	13	D	Dd. 105 ft.
602	E2d-4522	Pearson Park	Book & Proch	1957	1240	Dr	7-5	176	20-129	ℙh	Ss	4-30-57	120	20	Ps	
603	E2d-6937	Kenneth Lockhart	U. S. Dean	1957	1085	Dr		100	9	ℙh ℙco	Ss			10	D	Ca
604	E2d-3112	David Thomas	Book & Proch	1957	1210	Dr	6-5	260	19-130	ℙco	Ss		235	7	D	Ca
607	E2c-7732	Charles Miller	do.	1957	790	Dr	5	21	21	Qd	S G	5- 2-57	12.5	5	D	Dd. 21 ft.
608	E2c-8015	Joe Tricola	do.		1120	Dr	5	309	158	ℙco	Ss		190	4	D	Dd. 60 ft., Ca
611	E2c-3005	J. Mijavec	Hisey Drilling Company	1957	1080	Dr	6	90	86	ℙco	Ss	5- 1-57	12.24	80	D	Ca
612	E2d-7659	Laurel Joint School	Slaven		1260	Dr		389	145	ℙco	Ss		200	80	D	Dd. 6 ft.
614	E2d-6338	John Lukas	Book & Proch	1957	980	Dr	6	106	76	ℙco	Ss		67	24	D	Dd. 5 ft.
615	E2d-2224	Robert Dickson, Jr.	do.	1956	1000	Dr	6	66	24	ℙco	Ss		15		D	
619	E2d-2411	R. Dietterle	do.	1957	1230	Dr	7	67	28	ℙc	Sh		20		D	Ca

633	E2d-2719	Frank Moesta	Dittmer and Sons	1957	1185	Dr	6	76	21	Ph	Ss		36			
635	E2d-0407	Wilmington Public School	Parker Bros.	1957	1176	Dr	6	178	48	Pco	Ss		145	10	D	Dd. 15 ft., Ca
644	E2c-3512	P. Yacobony	Book & Proch	1956	1080	Dr	7	137		Pco	Sh	10-14-57	30.22		D	
647	E2d-4209	Evangelical U. B. Church	Dittmer and Sons	1957	1131	Dr	6	59	32	Ph	Ss Sh				Ps	
671	E2c-1357	A. J. Byler	Book & Proch	1957	1171	Dr	6	66	34	Pm	Ss Sh		17	8	D	Dd. 33 ft.
672	E2c-1852	Henry B. Byler	do.	1957	1058	Dr	6	93	25	Pco	Ss		46	24	D	Dd. 45 ft.
673	E2d-3304	Harold Green	do.	1957	1075	Dr	6	87	40	Pco	Ss		15	7	D	Dd. 72 ft.
679	E2d-4110		Parker Bros.	1957	1160	Dr	7	92	33	Ph	Ss		20		D	
682	E2d-4221	Harry Diehl	Elmer Book		1176	Dr		147	78	Ph	Ss		66	6	D	
707	E2d-7747	Fred Sickafuse	U. S. Dean		1172	Dr		78	63	Pv	Ls		67		D	
708	E2d-7748	E. Moore	do.		1177	Dr		52	42	Pkl	Sh		42		D	
715	E2d-7551	M. J. Pollio	Book & Proch		1169	Dr		96		Pcn					D	
729	E2d-7764	Hugh Forbes	do.	1958	1190	Dr	5	95	70	Pcn	Sh		65	12	D	
802	E2d-6852	Green	do.	1959	1195	Dr	6	84	84	Pcn Pv	S G		57	30	D	Ca
803	E2d-3607	Philip Winter	do.		1122	Dr	6	68	59	Pm	Ss Sh		30	20	D	Dd. 23 ft.
804	E2d-4503	William Johns	do.	1957	1100	Dr	6	76	31	Ph	Ss		39		D	
805	E2d-4715	G. Keller	do.	1959	1220	Dr	6	80	52	Pcn	Sh		32	24	D	Dd. 40 ft.
806	E2d-5206	Eli Stone	do.	1958	1055	Dr	6	93	20	Pco	Sh		16	6	D	Dd. 93 ft.
807	E2d-4017	W. Siebanoller	Parker Bros.	1958	1210	Dr	7	85	16	Ph	Ss		25	5	D	
810	E2d-4706	New Castle Country Club	Book & Proch	1958	1090	Dr	7	115	40	Pcou	Ss		32	20	D	Dd. 71 ft.
811	E2c-5750	Alfred Grimm	do.	1957	920	Dr	6	142	136	Ms	Ss		45		D	
814	E2d-6604	E. Minick	do.	1958	980	Dr	6	81	40	Pco	Ss		51	20	D	Dd. 10 ft.
815	E2d-6219	Merle Kelly	do.	1957	980	Dr	6	98	18	Pm Pco	Sh		25	4	D	Dd. 73 ft.
817	E2d-4646	D. L. Hudson	do.	1957	1075	Dr	6	81	58	Pco	Ss		50	24	D	Dd. 10 ft.
818	E2d-5342	W. B. Porada	do.	1957	1002	Dr	6	76	54	Pco	Ss		40	36	D	Dd. 0.0 ft.
822	E2c-4333	Charles E. Cox	do.	1957	1110	Dr	6-4	220	16-121	Pcol	Ss		70	1	D	Dd.
823	E2c-3512	John C. Phillians	do.	1957	1080	Dr	6	73	64	Pcol	Ss		25		D	
824	E2c-3815	Albert Serafino	do.	1957	1085	Dr	7	41	26	Pco	Ss		7		D	

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Table 2.—Record of wells (continued)

Well number	Location number	Owner	Driller	Date completed	Altitude above sea level (feet)	Method of construction	Diameter of casing (inches)	Total depth (feet)	Depth to bottom of casing (feet)	Aquifer		Static water level		Yield (gpm)	Use	Remarks
										Name	Composition	Date measured	Depth below land surface (feet)			
							LAWRENCE COUNTY—Continued									
La- 825	E2c-5538	S. Zoccoli	Dittmer and Sons	1957	990	Dr	6	78	25	ℙcol		8-28-57	18.06		D	
826	E2c-1505	David Luptak	do.	1959	990	Dr	6	79	49	Mh	Sh		37	5	D	Dd. 37 ft.
827	E2d-0401	John A. Byler	do.	1958	1210	Dr	6	50	45	ℙm	Sh		14		D	
831	E2d-6055	M. Rogers	Book and Proch	1959	1095	Dr	8-6	170	62 137	ℙco	Ss		99	30	D	Dd. 12 ft.
832	E2c-6302	Henry Fletcher	do.	1959	940	Dr	6	91	35	ℙcol	Ss		45	12	D	Dd. 15 ft.
838	E2c-4007	John Dieter	J. E. Scott	1960	1005	Dr	6	51	31	ℙcol			12		D	
839	E2c-5032	C. D. Ambrosia	Dittmer & Sons	1958	1075	Dr	6	107	56	ℙco	Sh			7	I	Dd. 98 ft.
841	E2c-5639	Tony Carbone	do.		990	Dr	6	70	48	ℙco	Sh			7	D	
845	E2c-6148	Penna. State Police	Glen McCreary	195	820	Dr	6-4	85	48 61	Ms	Ss		20	15	Ps	
847	E2d-4225	V. Moore	Book & Proch	1957	1030	Dr	8	129	10	ℙco	Ss		40		D	
848	E2d-1533	Charles Schaible	Dittmer & Sons	1958	1080	Dr	6	40	31	ℙco	Ss		33	20	D	
849	E2d-2543	Robert E. Fleming	do.	1957	980	Dr	4	46	36	ℙco	Ss			10	D	
850	E2d-1558	Girl Scout Camp	Glen McCreary	1958	1050	Dr	5	75	63	ℙco	Ss				D	
852	E2c-1502	A. Boodan	Dittmer & Sons		1040	Dr	6	53	21	ℙco	Sh		44	12	D	
853	E2c-3828	John Marco	Book & Proch	1960	1120	Dr	6 5	275	11 182	Ms	Ss		100	8	D	
854	E2c-7604	St. Lawrence Church	Dittmer & Sons	1956	1080	Dr	6	158	57	ℙco	Sh		91	5	Ps	

856	E1d-7158	Michael	Glen McCreary	1957	1045	Dr	6	60	24	Pco	Ss		8	D	
857	E2c-7401	Marshall McCree	Glen McCreary	1957	1110	Dr	6	95	21	Ph Pm	Ss	40	6	D	Dd. 40 ft.
858	E2c-8125	Walter Harmon	Dittmer & Sons	1957	980	Dr	6	92	18	Pco	Ss, Sh	29	5	D	
859	E2c-8423	Joe Salzman	do.	1958	1060	Dr	6	89	32	Pm	Sh	46	16	D	Dd. 0.0 ft.
861	E2c-7751	Contractor	Glen McCreary	1958	1130	Dr	6	95	23	Ph	Ss Sh	50	70	D	Dd. 20 ft.
864	E2c-7849	Louis Primavere	Dittmer & Sons	1956	1130	Dr	6	64	30	Pcn	Sh	4	5	D	
869	E2c-7664	William Stalnecker	Glen McCreary	1957	990	Dr	6	40	25	Pcou	Ss	12	12	D	Dd. 6 ft.
872	E2d-1845	William Allen	T. Powell	1960	1060	Dr	4	93	87	Pco	Ss	53	10	D	Dd. 14 ft.
873 4d	E2d-2429	James Elder	Dittmer & Sons	1958	950	Dr	6	155	154	Qd	S, G	17	25	D	Dd. 23 ft.
874	E2d-6125	Wilson	Elmer Book	1959	1125	Dr	5	130	78	Pm	Sh	45	5	D	Dd. 10 ft.
879	E2d-2954	Albert A. McGary	V. Palmer	1960	1170	Dr	7	64	34	Pm	Sh	30	20	D	
883	E2d-4224	Robert H. McBurney	Book & Proch	1960	1140	Dr		211		Pcou	Ss	174	8	D	
884	E2d-4823	Mike Alick	do.	1960	1240	Dr	6-4	216	15 188	Pco	Ss Sh	115	12	D	Dd. 25 ft.
885	E2d-5024	Harold Robertson	do.	1960	1235	Dr	6-4	326	117	Pcol	Ss	265	8	D	Dd. 25 ft.
886	E2c-8117	Adolph Buber	do.	1960	110	Dr		162		Pcn	Ss			D	
887	E2c-3928	A. Gould	do.		1125	Dr	7		112	Pco	Ss Sh	89	14	D	Dd. 70 ft.
888	E2d-0759	Volant Boro	do.		1160	Dr	8	285		Ms	Ss			Ps	
889	E2c-7549	Ann's Food Castle	Dittmer	1960	1105	Dr	6	66	35	Pcn	Sh	8	9	Ps	Dd. 46 ft.
890	E2c-2904	James Patterson	do.	1960	1145	Dr	6	45	31	Ph	Ss	12	15	D	Dd. 8 ft.
891	E2c-0116	Frank Kohansky	do.	1960	1135	Dr	6	80	16	Pco	Ss	40	15	D	
892	E2c-7853	James Moses	do.	1960	1145	Dr	6	85	42	Pcn	Sh		9	D	
895	E2d-7842	R. Clements	U. S. Dean		1250			130		Pv	Ls			D	
898	E2c-2353	Lawrence Vogan	Parker Bros.	1961	865	Dr	6	210	120	Mo	Sh	120	6	D	Dd. 90 ft.

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Table 2.—Record of wells (continued)

Well number	Location number	Owner	Driller	Date completed	Altitude above sea level (feet)	Method of construction	Diameter of casing (inches)	Total depth (feet)	Depth to bottom of casing (feet)	Aquifer		Static water level		Yield (gpm)	Use	Remarks
										Name	Composition	Date measured	Depth below land surface (feet)			
LAWRENCE COUNTY—Continued																
902	E2c-7934	Vanport Stone Co.	Book & Proch		790	Dr		128		Qd	S G		16	30	D	Dd. 10 ft.
905	E2c-3352	James Braho	Dittmer	1960	895	Dr	6	61	48	Ms	Ss		40	16	D	Dd. 6 ft.
907	E2c-6430	Contractor	do.	1960	1000	Dr	6	114	66	Ms	Sh		72	5	D	Dd. 37 ft.
909	E2c-4662	Thomas Ratvasky	do.	1960	890	Dr	6	87	62	Ms	Ss		33	16	D	Dd. 34 ft.
910	E2c-7640	Joseph Dadejko	do.	1958	913	Dr	6	144	89	Ms	Ss		83	6-7	D	Dd. 56 ft.
MERCER COUNTY																
Mr- 362a	E2b-3249	Charles Sines			1328	Du	36	32		Qd	S G	9-21-55	13.87		D O	
362b	E2b-3249	do.	Parker Bros.	1960	1328	Dr	7	105	55	Pcn	Sh		55	5	D	
366	E2b-0340		do.	1955	1071	Dr	6	350	256	Mo	Sh	7-12-55	61.77		A O	0-256 glacial deposit
368	E2b-1120	Kirkland	Virgil Palmer	1955	1287	Dr	6	73	20	Pco	Ss	7-13-55	26.05	4-5	D	
369	E2b-0804	C. B. Clevenger	do.	1955	1221	Dr	7	117	96	Pm	Sh	7-13-55	7.50	28	D	
378	E2b-3760	L. S. Stull	Floyd Offut	1955	1153	Dr	4	123	105	Pcol	Ss Sh	7-22-55	20.90	10	D	
380	E2a-3401	Sawhill Tubular Products Shenango Agaloy Division	Lininger Bros.	1953	946	Dr	8	306		Mc	Ss		24	75	I	
470	E2b-1055	George Thompson	George Thompson		1265	Dr	6	31	18	Ph	Ss	7-10-58	14.20		D	Ca

508	E2a-1335	Jerry Milks	Parker Bros.	1956	1200	Dr	7	103	33	ℙco	Sh		35		D	
510	E2a-4823	Schroll	do.	1955	840	Dr	7	170	150	Mo	Sh		15			0-150 ft. glacial deposit
827	E2b-4550	O. R. Thompson	Floyd Offutt	1957	1280	Dr	5	75	55	ℙh	Ss		40	10	D	
834	E2b-7728	R. J. Wells	Book & Proch	1957	985	Dr	6	75	75	Qd	S G		4	4	D	Dd. 70 ft.
838	E2b-6616	Edward Miller	Dittmer & Sons	1957	1240	Dr	6	81	40+	ℙh	Ss	6-20-57	53.60	17	D	
854	E2a-6118	H. G. Grace	Hisey Drilling Co.	1957	1050	Dr	6	80	26	ℙs Mh	Ss Sh		31			
864	E2a-0331		Parker Bros.	1957	1140	Dr	7	130	15+		Ss	8- 6-57	97			
869	E2b-0155	Fred Drapola	do.	1957	1300	Dr	7	65	41	ℙh ℙco	Ss		30	30	D	Dd. 10 ft.
875	E2b-1459	Dealton M. Redic	Floyd Offutt	1955	1280	Dr	6	72	62	ℙm	Sh		20	10	D	
876	E2b-6114	Charles H. Perry, Jr.	Parker Bros.	1957	1270	Dr	6	70	58	ℙcou	Ss		22		D	
877	E2b-1564	Michael E. Wester	do.	1957	1270	Dr	7	110	63	ℙcou	Sh	8-14-57	43.20	15	D	
878	E2a-4132	Harold Turner	do.	1957	1030	Dr	7	200	168	Mm	Sh		75	5	D	0-171 ft. glacial deposit
881	E2a-5745	Frank McCroy	do.	1957	1100	Dr	7	115	22	ℙs	Sh		40	15	D	
892	E2a-7659	C. Wallace	do.	1957	1190	Dr	7	106	58	ℙcou	Ss	9- 6-57	12.27		D	
897	E2a-6438	Matthew Stefanak, Jr.	W. McDowell	1957	1040	Dr	6	153	41	ℙcol	Ss		70	35	D	
903	E2a-7847	Wm. R. Gatewood	George Book	1954	1160	Dr	5	35	33	ℙm	Sh		10		D	
908	E2a-6146	N. Stefanak	Parker Bros.	1957	1120	Dr	7	50	20	ℙcou	Ss Sh	9-10-57	7.43	40	D	
921	E2a-5335	J. Tribby	do.	1957	980	Dr	7	90	45	Mm	Sh		20		D	
925	E2a-0203	Vern Seem	do.	1957	1160	Dr	7	355	52	Mm	Sh		40		D	
931	E2a-1326	Garrett's Gulf Station	do.	1957	1100	Dr	7	110	33	ℙs	Sh Ss	1- 6-57	21.19	7	D	
963	E2b-1945	J. D. English	Parker Bros.	1957	1252	Dr	7	153	32	ℙco	Ss				D	
964	E2b-2354	George Michael	V. Palmer	1958	1155	Dr	7	101	100	Qd	G		45		D	

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Table 2.—Record of wells (continued)

Well number	Location number	Owner	Driller	Date completed	Altitude above sea level (feet)	Method of construction	Diameter of casing (inches)	Total depth (feet)	Depth to bottom of casing (feet)	Aquifer		Static water level		Yield (gpm)	Use	Remarks
										Name	Composition	Date measured	Depth below land surface (feet)			
						MERCER COUNTY—Continued										
Mr- 968	E2b-2647	David Webster	J. E. Lininger and Sons	1957	1385	Dr	8-7	180	118	ℙh ℙm	Ss Sh		124		D	Ca
978	E2a-5223	West Middlesex Boro.			836	Dr	10-8	316	205	Mc	Ss		8-10	100	Ps	
1027	E2b-1565	John Alderson	V. Palmer	1958	1245	Dr	7	85	62	ℙcou	Ss		45	10	D	
1074	E2a-5600	John Yourga	Parker Bros.	1959	1040	ℙm Dr	8 6-7	460	188	Mc	Ss	3-18-59	315	20	A	Ca
1202	E2a-1627	Holy Trinity Church	do.	1959	1125	Dr	8	144	48	ℙs	Sh		40	10	D	
1203	E2a-2026	Peter Dobrowalski	J. E. Lininger and Sons	1959	1122	Dr	7	100	43	ℙs	Ss Sh		30	4-7	D	
1216	E2a-3758	J. David	Parker Bros.	1958	1080	Dr	7	47	47	ℙs	Ss		5	10	D	
1217	E2a-3563		do.	1959	1220	Dr	7	75	27	ℙm	Sh		28	8	D	
1219	E2a-1848	Robert Schaller	do.	1958	1200	Dr	6	105	50	ℙco	Sh		30	10	D	
1226	E2a-5515	William Young	do.	1957	1026	Dr	7	75	23	ℙs	Sh		40	10	D	
1228	E2a-8125	Mike Pajanak	do.	1956	1123	Dr	7	88	23	ℙcou	Ss		30		D	
1229	E2a-6609	Stanley Smith	do.	1957	1118	Dr	6	80	24	ℙco	Sh		50		D	
1236	E2b-1615	Mobile City Trailer Park	do.	1957	1280	Dr	8	130	42	ℙh ℙcou	Ss		20		D	
1237	E2b-2412	N. E. Peterson	do.	1958	1305	Dr	7	100	20	ℙh	Ss		57	15	D	Dd. 13 ft.
1238	E2a-5557	T. Minner	do.	1957	1100	Dr	7	80	37	ℙco	Ss	10-10-57	18.64	10	D	

1239	E2a-0643	R. W. Brown	do.	1957	1149	Dr	8-7	160	96	ℙs	Ss	30	15	D	Dd. 30 ft.
1240	E2a-2554	W. Estman	do.	1957	1120	Dr	7	145	127	ℙs	Sh Ss	100		D	
1241	E2a-1254	Mark Dzapo	do.	1958	1180	Dr	7	80	35	ℙco	Ss	10	10	D	
1244	E2b-0906	J. E. Moore	do.	1959	1260	Dr	7	70	24	ℙh	Ss	25	10	D	
1245	E2b-2708	Paul Shipton	do.	1957	1280	Dr	6	95	42	ℙm	Sh	20	10	D	
1247	E2b-3507	James Dolon	do.	1957	1280	Dr	7	140	62	ℙcou	Ss	70	5	D	
1248	E2b-3206	George Walter	Parker Bros.	1957	1275	Dr	7	110	41	ℙh ℙm	Ss Sh	48		D	
1249	E2b-0908	M. Murko	do.	1957	1260	Dr	7	90	23	ℙh	Ss	30		D	
1251	E2a-3855	Barris	do.	1958	1100	Dr	6	115	31	ℙco	Ss	20	15	D	Dd. 40 ft.
1252	E2a-2843	Albert Snyder	do.	1959	1140	Dr	7	110	71	ℙs	Sh	25	4	D	
1254	E2a-2041	J. Rollinson	do.	1959	1145	Dr	7	80	30	ℙco	Sh	3	15+	D	
1255	E2a-2930	Martin Schumacher	W. McDowell	1957	1140	Dr	6	125	46	ℙco	Sh	50	2	D	
1259	E2a-4840	S. Jones	Parker Bros.	1959	1090	Dr	7	80	60	ℙco	Ss Sh	10		D	
1260	E2a-4734	Harry Rabold	do.	1957	1135	Dr	7	140	104	ℙco	Sh	70		D	
1262	E2b-1901	Horvath Dairy	do.	1959	1215	Dr	7	38	38	Qd	S	10	50	I	
1263	E2b-1902	B. Ellis	do.	1957	1220	Dr	7	39	38	ℙh	Ss	15	15	D	
1264	E2b-1704	Horvath Dairy	do.	1958	1245	Dr	7	67	53	ℙh	Ss	20	15	D	
1265	E2a-0764	George Plummer	do.	1958	1245	Dr	7	90	18	ℙh	Ss	30	12	D	Dd. 60 ft.
1268	E2a-0864	Miller S. Heath	do.	1957	1240	Dr	7	90	19	ℙh ℙm	Ss Sh	20	6	D	
1270	E2b-2258	A. A. Sharlow	W. McDowell	1948	1300	Dr	5	90	78	ℙm	Sh	45	20	D	
1271	E2b-3737	Austin Wieand	do.	1945	1240	Dr	5	71	27	ℙco	Ss	28	20	D	Dd. 8 ft.
1272	E2b-2533	Wilbur Rucker	do.	1945	1220	Dr	5	136	40	ℙco	Ss	98	10	A	
1273	E2b-1446	John Kirkpatrick	do.	1954	1220	Dr	7	120	17	ℙco	Ss	91	30	D	
1276	E2b-1453	Paul Mortland	Parker Bros.	1958	1215	Dr	7	112	19	ℙcou	Ss Sh	25	6	D	

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Table 2.—Record of wells (continued)

Well number	Location number	Owner	Driller	Date completed	Altitude above sea level (feet)	Method of construction	Diameter of casing (inches)	Total depth (feet)	Depth to bottom of casing (feet)	Aquifer		Static water level		Yield (gpm)	Use	Remarks
										Name	Composition	Date measured	Depth below land surface (feet)			
MERCER COUNTY—Continued																
Mr- 1277	E2b-1035	W. F. Swingle	do.	1956	1150	Dr	7	139	15	Ms	Ss		75		D	
1278	E2b-6759	D. Heckathorn	W. McDowell	1954	1185	Dr	7	60	21	ℙcou	Ss		30	60	D	
1279	E2b-1863	Ralph Olds	Parker Bros.	1956	1250	Dr	7	115	58	ℙm	Sh		65		D	
1280	E2b-3119	Wm. Schreckengost	do.	1955	1300	Dr	7	80	28	ℙh	Ss		7		D	
1282	E2b-7719	Edward C. Marshalls	Parker Bros.	1958	1025	Dr	7	100	57	Ms	Sh		20	5	D	
1284	E2a-6651	Paul Gathers	Hisey Drilling Co.	1959	1175	Dr	6	83	28	ℙm	Sh		10	20	D	Dd. 30 ft.
1285	E2b-4005	Gault	V. Palmer	1958	1270	Dr	7	130	41	ℙm	Sh		50	7	D	
1287	E2b-7309	Gerald Artman	do.		1020	Dr	7	70	41	Mh	Sh		9	40	D	
1288	E2b-8019	Wm. Osborne	do.	1959	1090	Dr	7	72	42	ℙs	Sh Ss		47	20	D	
1290	E2b-8221	Wm. Burbicks	do.	1958	1070	Dr	7	70	36	ℙs	Ss		42	20	D	
1292	E2b-7718	Harold Elliot	Parker Bros.	1959	1025	Dr	7	103	19	Ms	Sh		50		D	
1293	E2a-1637	Perry Patton	do.	1957	1155	Dr	7	81	70	ℙco	Sh		45	15	D	
1297	E2a-1732		do.	1958	1120	Dr	7	130	92	ℙs	Ss Sh		30	10	D	Dd. 13 ft.
1299	E2a-1660	Howard Shipton	do.	1958	1150	Dr	7	90	67	ℙs	Sh		30		D	
1300	E2a-1159	John Hines	do.	1958	1120	Dr	7	120	115	Mh	Sh		40		D	
1301	E2a-3622	Beachmont Club	do.	1958	900	Dr	7	184	21	Mm	Sh		10	12	Ps	

1304	E2a-0339	Walter Perman	do.	1958	1120	Dr	6	155	85	Ms	Ss	104		D	
1305	E2b-5717	Dan Hostetter	do.	1959	1265	Dr	7	75	47	ℙs	Ss	35	4	D	
1306	E2a-5351	Mark Lisac	Book & Proch	1958	1140	Dr	6	110	83	ℙco	Ss	30	20	D	Dd. 60 ft.
1310	E2b-1015	Russell Davidson	Parker Bros.	1959	1295	Dr	7	115	23	ℙm	Sh	23	7	D	
1311	E2b-3324	Paul F. Book	do.	1960	1285	Dr	7	125	23	ℙh ℙm	Ss Sh	69	10	D	
1312	E2b-5125	E. V. Evans	Francis McCullough	1958	1240	Dr		85	10	ℙco	Ss	2		D	
1314	E2a-5605	Stenoff	Hisey Drilling Co.	1959	1051	Dr	6	70	46	ℙco	Sh	25	30	D	Dd. 10 ft.
1315	E2a-6702	Thompson	do.		1091	Dr	6	175	29	Ms	Ss		12	D	
1317	E2b-4465	LeRoy Drake	Floyd Offutt		1165	Dr		45	45	Qd	G	25	20	D	
1319	E2b-5555	O. Rogers	do.		1195	Dr		59	33	ℙco	Ss	30	16	D	
1322	E2b-3143	R. D. Heazlett	do.		1290	Dr		108	92+	ℙco	Ss	50	10	D	92 ft to bedrock
1325	E2b-7255	Harold Shannon	V. Palmer	1959	1275	Dr	7	75	66	ℙcn	Sh	22	21	D	
1329	E2b-0751	J. Yohman	Parker Bros.	1960	1220	Dr		82		ℙco	Ss	35	10	D	
1331	E2b-0600	Calvin Straight	do.		1220	Dr		102	80	ℙco	Sh	30	15	D	Dd. 10 ft.
1332	E2b-0163	County Home	J. E. Lininger and Sons	1960	1220	Dr	10	100	69	ℙco	Ss	8	90	D	
1334	E2a-8236	B. B. Ellis	do.	1960	903	Dr	7	352	75	Mb	Ss	93		D	
1338	E2a-6242	W. Campbell	Parker Bros.	1960	1130	Dr	7	92	21	ℙco	Ss	30	10	D	
1341	E2a-1038	Ronald Lee	do.	1960	1265	Dr	7	150		ℙco	Sh	50	15	D	
1343	E2a-2536	Rogers	do.	1960	1180	Dr	7	196	15	ℙco ℙs	Ss Sh	110	15	D	
1346	E2b-1662	Mercer Tire Company	V. Palmer		1250	Dr	7	80	18+	ℙm	Sh			D	
1349	E2a-2556	E. Hoffman	Parker Bros.	1961	1130	Dr	7	160	111	Mh	Ss Sh	50	15	D	Dd. 10 to 15 ft.
1350	E2a-0749	Richard White	do.	1961	1210	Dr	7	95	25+	ℙco	Ss	10	15	D	Dd. 60 ft.
1351	E2a-0653	W. White	do.	1961	1170	Dr	7	85	40	ℙcol	Ss	45	15	D	
1352	E2a-3149	Howard Foster	do.	1961	1165	Dr	7	110	32	ℙcol	Ss	40	5	D	
1354	E2b-1353	Frank Miller	Floyd Offutt		1265	Dr		70	25+	ℙh	Ss	65		D	
1360	E2a-1615	Frank Babais	Parker Bros.	1961	1140	Dr	7	105	15	ℙco	Ss Sh	40	7	D	
1362	E2a-0305	Wall	do.	1961	1063	Dr	7	210	30	Mm	Sh	85	6	D	Dd. 120 ft.
1363	E2a-8640	Elmer Gurtner	Dittmer & Sons	1960	970	Dr	6	50	26	ℙs	Sh	23	10	D	Dd. 17 ft.

Table 3.—Chemical analyses of ground water

Aquifer name: ℙkl, Kittanning Formation, lower member; ℙv, Vanport Limestone; ℙcn, Clarion Formation; ℙh, Homewood Formation; ℙco, Connoquenessing Formation, undifferentiated; ℙcou, Connoquenessing Formation, upper member; ℙcol, Connoquenessing Formation, lower member; Mc, Cussewago Sandstone.
Results in parts per million except temperature, field hardness, specific conductance, and pH.

Well number	Aquifer	Date of collection	Temperature °F	Silicia (SiO_2)	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids (calculated)	Hardness as $CaCO_3$		Specific conductance micromhos per meter at 25°C		pH	
																	Calcium-magnesium	Non-carbonate	Laboratory	Field	Laboratory	Field
									MERCER COUNTY													
Mr- 470	ℙh	9-23-59	54	12	0.38	0.20	48	9.0	3.6	1.3	188	15	1.7	0.3	0.3	184	157	3	340		7.3	
968	ℙh	5- 4-59		9.8	.29	.02	77	16	4.0	7.0	306	25	1.0	.2	4.8	296	258	7	496		7.3	
978	Mc	5- 5-59		10	.10	.00	4.0	1.9	290	5.0	342	2.0	270	.6	.4	752	18	0	1,360		8.0	
1074	Mc	5- 5-59	56	10	.81	.00	3.2	1.9	400	5.0	438	0	330	.4	.4	967	16	0	1,720		8.5	
									LAWRENCE COUNTY													
La- 461	ℙcol	9-28-59		8.4	0.32	0.03	70	20	12	6.0	330	20	5.7	0.0	3.1	308	257	0.0	559		7.4	
541	ℙcol	9-23-59		8.2	1.7	.10	98	43	7.5	4.9	474	46	1.2	.2	1.3	444	422	33	731		7.0	
560	ℙcol	9-28-59		8.0	1.4	.03	11	3.8	154	10	434	1.2	8.8	.4	.9	412	43	0	634		7.5	
603	ℙh ℙcou	9-23-59	51	8.9	2.1	.20	64	13	4.3	2.5	238	28	1.8	.0	.4	240	213	18	406	425	6.9	7.2
604	ℙco	9-23-59	61	7.5	.02	.02	22	7.3	164	18	520	2.8	12	.5	.1	490	85	0	770	650	7.7	7.9
608	ℙcol	9-23-59	55	8.8	.16	.02	3.3	1.9	470	5.0	788	7.9	270	1.5	.2	1,160	16	0	1,960	1,200	7.8	8.4
611	ℙcou	9-23-59		8.6	7.5	.24	80	17	19	2.0	289	59	2.9	.0	.1	331	270	33	737		6.9	
619	ℙcn	9-28-59		9.4	0.83	0.08	61	16	4.3	3.3	274	12	1.4	.4	0.1	243	218	0.0	463		7.4	
635	ℙcou	9-23-59		7.6	.13	.05	68	17	19	7.0	323	18	2.6	3.	.5	299	240	0	547		7.5	
802	ℙv	9-23-59		17	2.2	.37	116	33	7.3	1.3	470	67	3.6	.1	.1	478	425	40	773		7.2	

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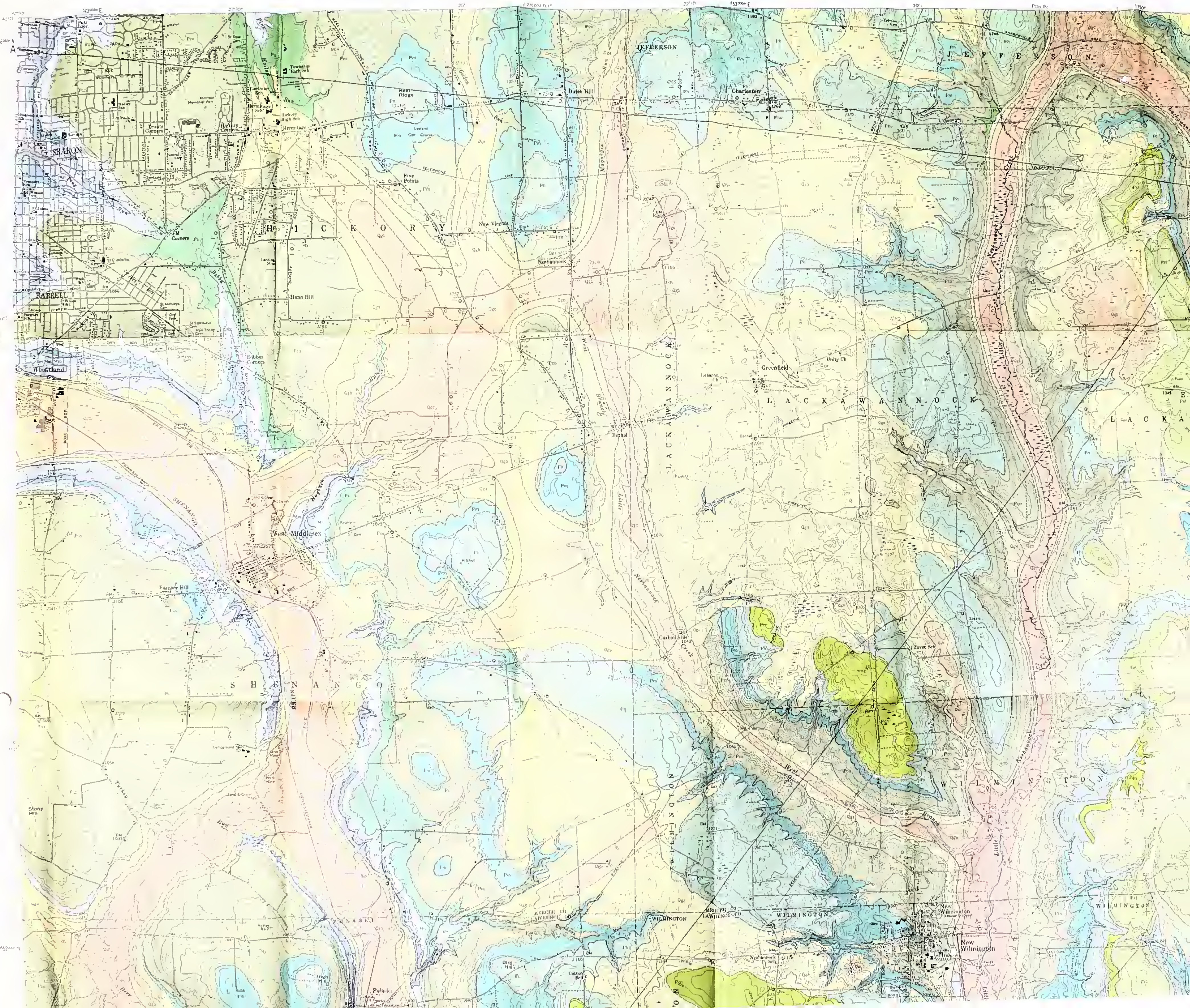
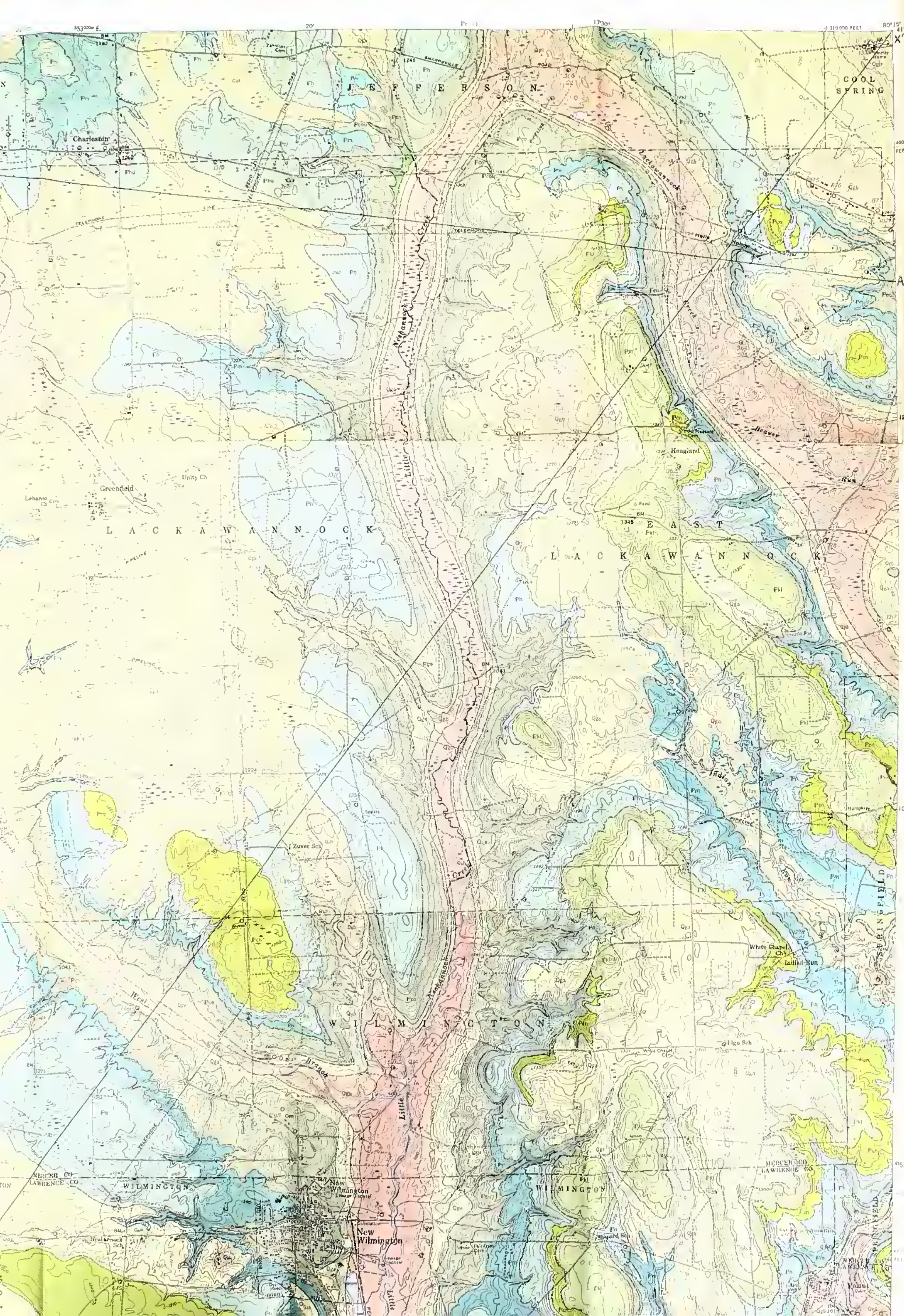
PENNSYLVANIA GEOLOGICAL SURVEY





EXPLANATION

sp

SPOIL PILES

Spoil piles from strip mining are identified as to the bed mined by: spk, lower Kittanning coal or fire clay; spv, Vanport Limestone; spc, Clarion coal; spm, a Mercer coal; sps, Sharon coal; spcl, deposits of clay.

Qga	Qgb	Qgc

GLACIAL DEPOSITS

Glacial deposits, included Recent alluvium in stream valleys. Deposits are subdivided according to thickness and not composition, geomorphic form, or genesis: Qga, 25 to 50 feet to bedrock; Qgb, 50 to 100 ft. to bedrock; Qgc, over 100 ft. to bedrock. Uplands are characteristically till covered, small valleys and flanks of valleys contain outwash (sand and gravel), central parts of major valleys are characteristically filled with silt and clay. Glacial deposits are not extensively utilized as a source of ground water in this area, but at New Wilmington yield over 300 gallons per minute.

QUATERNARY

ALLEGHENY GROUP

Pku
Pkm
Pkl

KITTANNING FORMATION

Alternating sequences of coal, clay, shale, and sandstone; divided into three members each having a coal at the top. Upper member, Pku, sandy shale and silty sandstone; middle member, Pkm, coal, shale, and sandy shale; lower member, Pkl, coal, clay, and shale, represented locally (in part or entirely) by channel-fill sandstone that may replace the underlying Vanport and Clarion Formations. Yields water for domestic use.

Pv

VANPORT LIMESTONE

Light-gray, locally dark-gray, dense limestone having a threaded appearance on weathered surfaces. Yields hard water for domestic use.

Pcn

CLARION FORMATION

Gray to greenish-gray shale and sandy shale, coal, and underclay; locally grades laterally into micaceous sandstone. Yields water for domestic use.

POTTSVILLE GROUP

Ph | Phu
Ph | Phl

HOMEWOOD FORMATION

Typically medium-grained sandstone in the lower part and shale in the upper part, but changing laterally from entirely sandstone to predominantly shale and siltstone. Locally the sandstone unit is shown as Phl, and the shale unit as Phu. Yields water for domestic use.

Pm

MERCER FORMATION

Dark-gray shale containing up to three coal beds, two of which are characteristically overlain by dark-gray, dense limestone beds, locally, shale between the limestone beds is replaced in part by channel-fill sandstone. The formation pinches out laterally in some areas where channel-fill sandstones of the Homewood and Connoquenessing Formations coalesce. Yields water for domestic use.

Pco

CONNOQUENESSING FORMATION

Two medium-grained, cross-bedded sandstone beds separated by dark-gray shale containing a coal. Intervening shale is locally missing so that sandstone occupies the entire interval; in other areas the formation consists predominantly of shale and silty shale. Yields water for domestic use, and locally for public use where interval is largely sandstone.

Ps

SHARON FORMATION

Includes a lower conglomeratic member and an upper shale member which locally contains a coal. The Formation can be recognized only in the northwest part of the quadrangle where the conglomeratic member is present. Yields water for domestic use.

PENNSYLVANIAN

Mh

HEMPFIELD SHALE

Interbedded shale, siltstone, and thin beds of fine-grained sandstone. Yields water for domestic use.

Ms

SHENANGO SANDSTONE

Medium-bedded, planar to cross-bedded, light-gray sandstone; weathered surfaces are dark olive brown. Yields water for domestic use and small public supplies.

Mm

MEADVILLE SHALE

Interbedded gray shale, silty shale, siltstone, and fine-grained sandstone. Yields water for domestic use.

Msh

SHARPSVILLE SANDSTONE

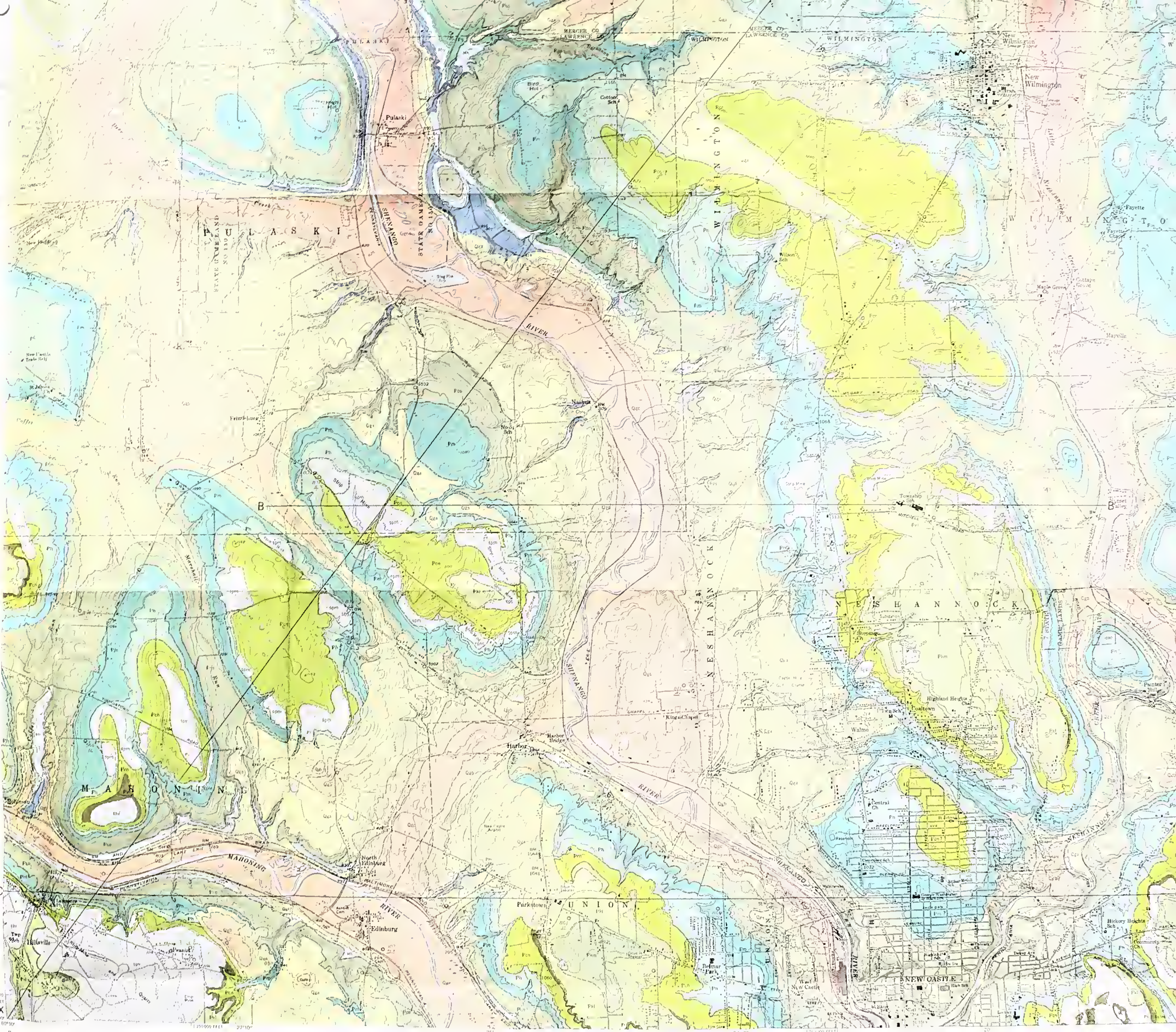
Fine-grained, light-gray, typically planar-bedded sandstone locally interbedded with shale and siltstone. Yields water for domestic use.

MISSISSIPPIAN

Contact, dashed where approximate, short dashed where gradational, indefinite, or inferred, dotted where concealed

WELLS

Numbers refer to those wells appearing in Table 1. Figures underlined show depth to bedrock.



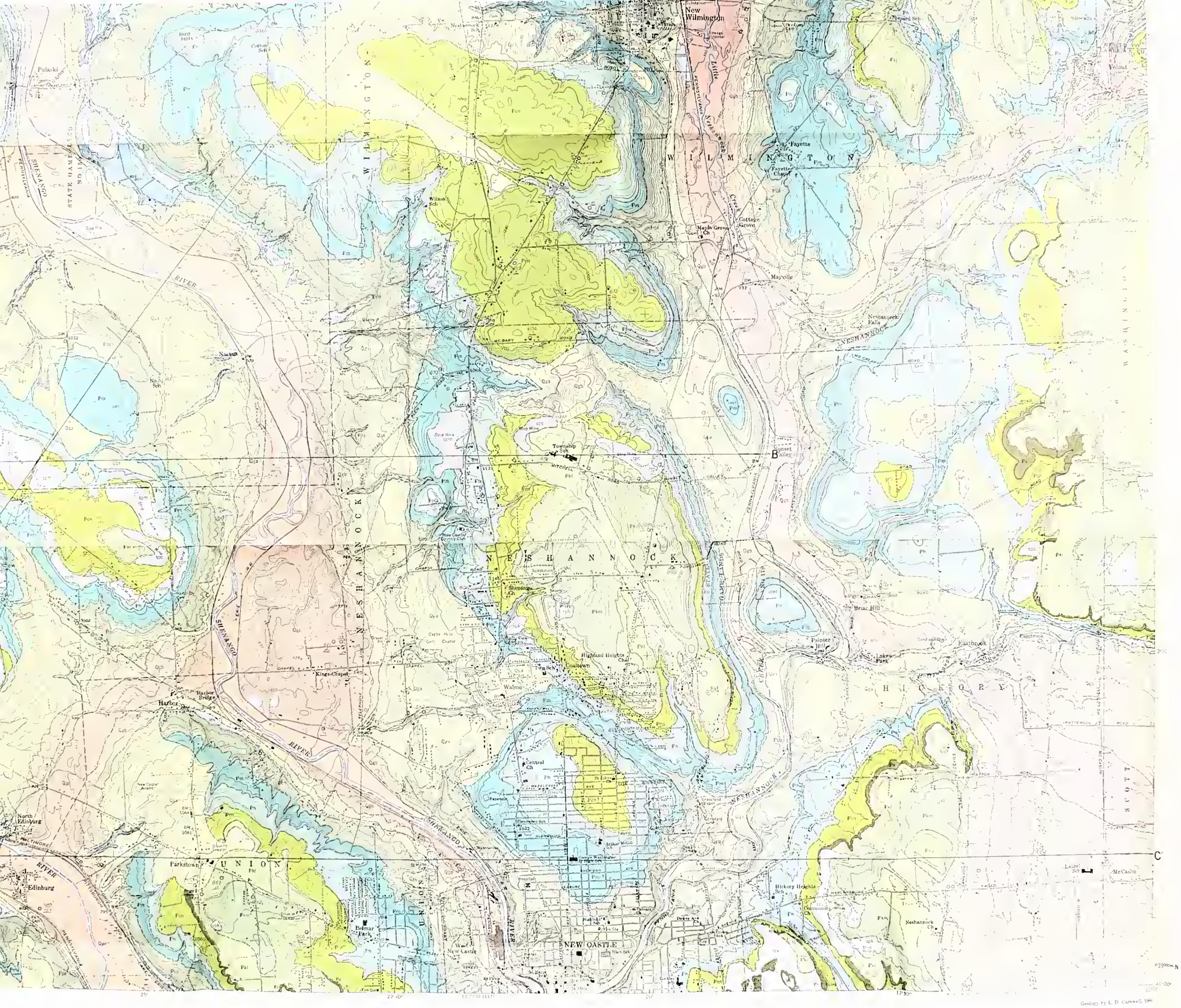
Base map from U. S. Geological Survey
7½' quadrangles, 1958.

APPROXIMATE MEAN
DECLINATION, 1958

GEOLOGIC MAP OF THE NESHANNOCK QUADRANGLE, PENNSYLVANIA

SCALE 1:24000

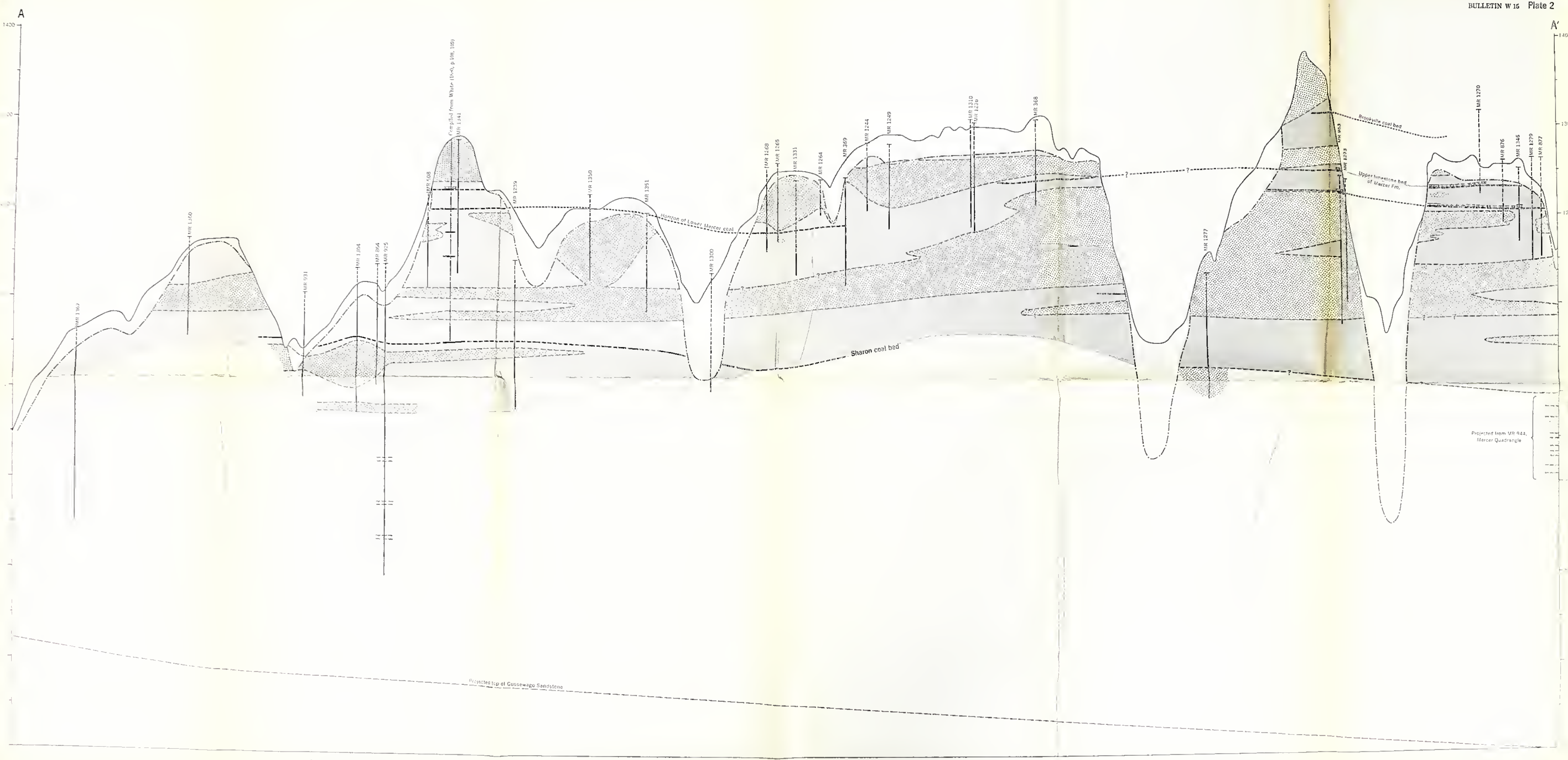
CONTOUR INTERVAL 10 FEET
DATUM IS MEAN SEA LEVEL



GEOLOGIC MAP OF THE NESHANNOCK QUADRANGLE, PENNSYLVANIA

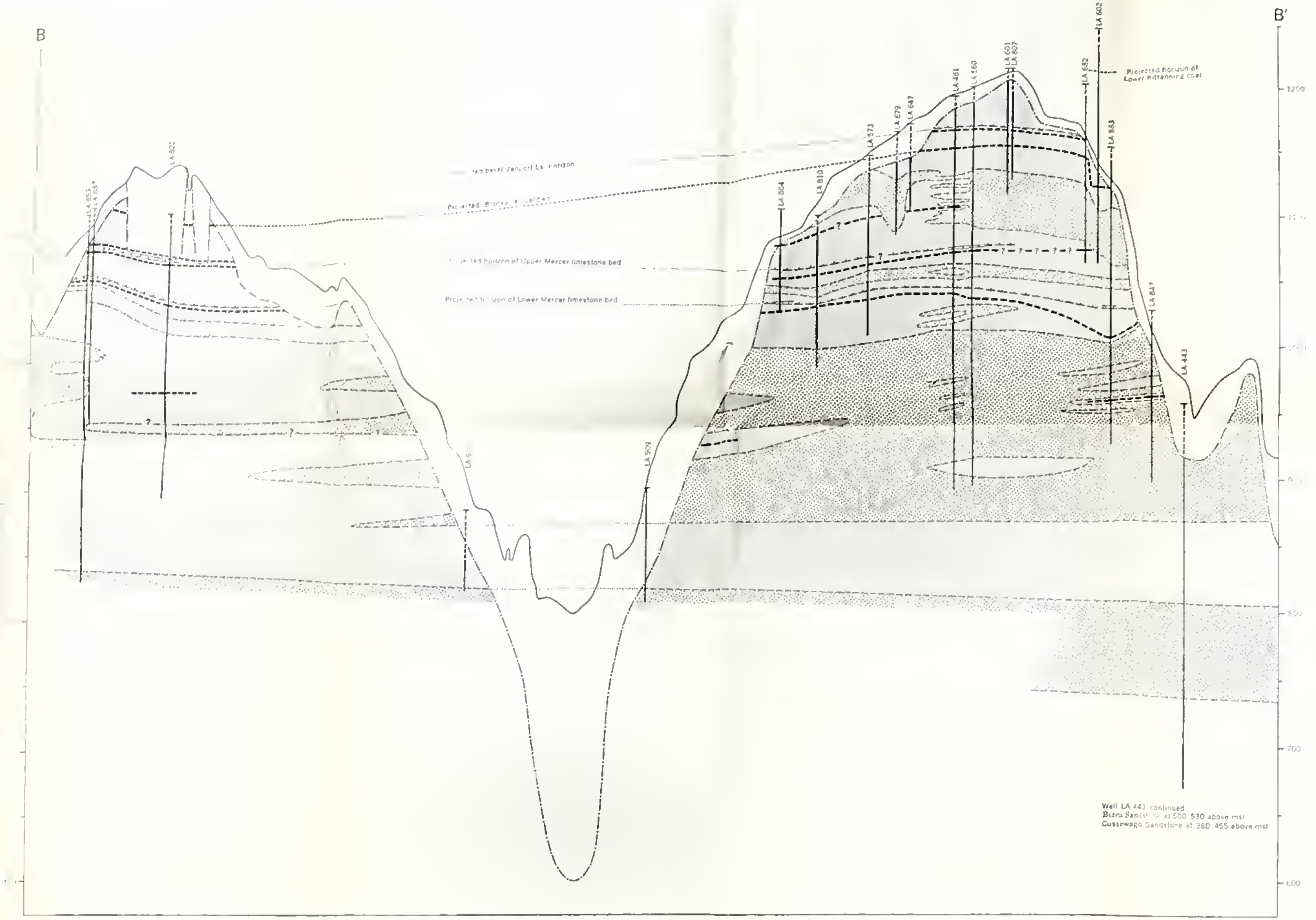
SCALE 1:24 000

CONTOUR INTERVAL 10 FEET
DATUM IS MEAN SEA LEVEL

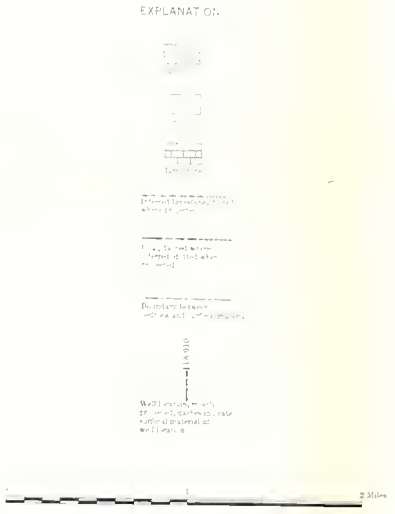


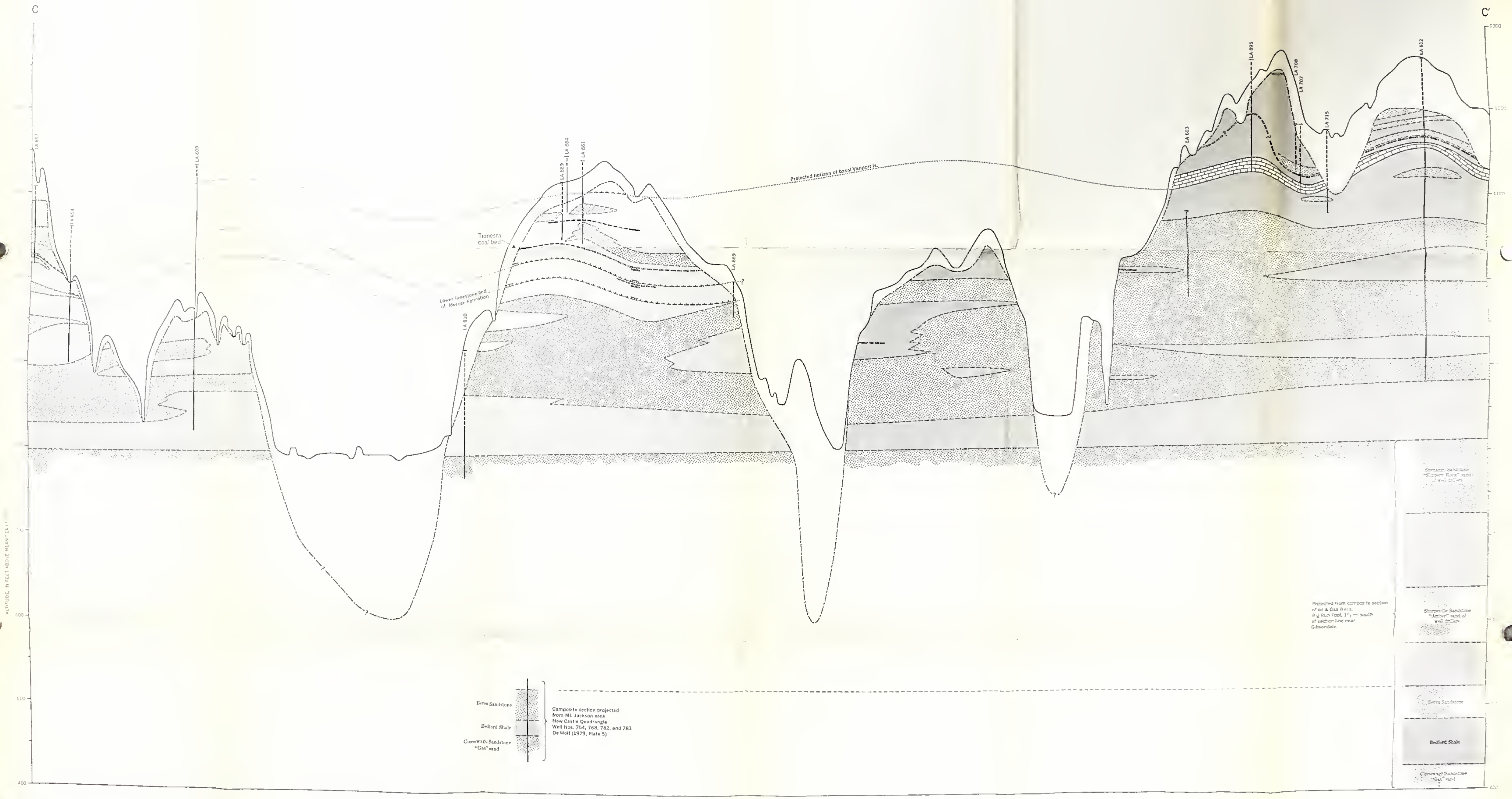
GENERALIZED GEOLOGIC CROSS SECTION ALONG LINE A-A' NORTHERN NESHANNOCK QUADRANGLE, MERCER COUNTY, PA.

(SEE Plate 1 FOR LOCATION OF SECTION)


B
B′
LA 863
LA 857
LA 822
LA 5
LA 909
LA 804
LA 810
LA 573
LA 679
LA 647
LA 461
LA 460
LA 601
LA 607
LA 682
LA 602
LA 833
LA 847
LA 443
Projected horizon of Lower Kittanning coal
Projected basal Vanport Ls. horizon
Projected Brookville coal bed
Projected horizon of Upper Mercer limestone bed
Projected horizon of Lower Mercer limestone bed
?
1200
1100
1000
900
800
700
600
Well LA 443 continued
Berea Sandstone at 500–530 above msl
Cussewago Sandstone at 380–455 above msl

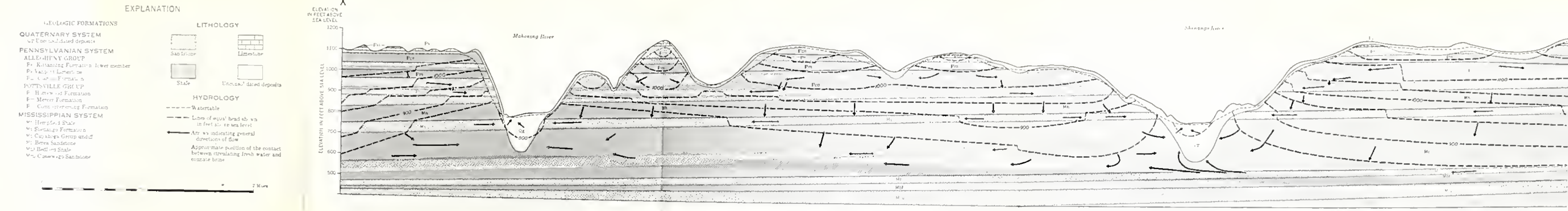
GENERALIZED GEOLOGIC CROSS SECTION ALONG LINE B-B′
NESHANNOCK QUADRANGLE, LAWRENCE COUNTY, PA.
(SEE Plate 1 FOR LOCATION OF SECTION)





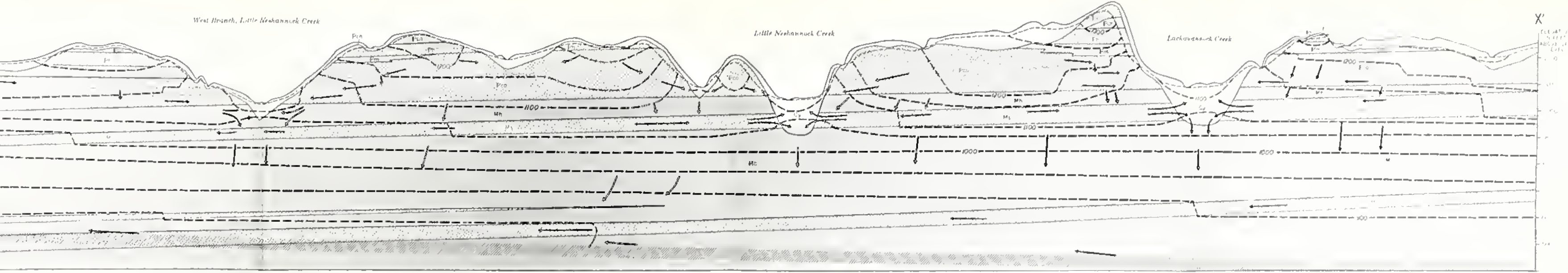
C
C′
LA 857
LA 854
LA 608
LA 910
LA 889
LA 864
LA 861
LA 869
LA 603
LA 895
LA 707
LA 708
LA 715
LA 612
Tionesta coal bed
Lower limestone bed of Mercer Formation
Projected horizon of basal Vanport ls.
ALTITUDE, IN FEET ABOVE MEAN SEA LEVEL
1300
1200
1100
600
500
400
Berea Sandstone
Bedford Shale
Cussewago Sandstone "Gas" sand
Composite section projected from Mt. Jackson area New Castle Quadrangle Well Nos. 754, 768, 782, and 783 De Wolf (1929, Plate 5)
Projected from composite section of oil & Gas Wells, Big Run Pool, 1½ mi south of section line near Gibsondale.
"Slippery Rock" sand of well drillers
Sharpsville Sandstone "Amber" sand of well drillers
Berea Sandstone
Bedford Shale
Cussewago Sandstone "Gas" sand

GENERALIZED GEOLOGIC CROSS SECTION ALONG LINE C-C′ NESHANNOCK QUADRANGLE, LAWRENCE COUNTY, PA.
(SEE Plate 1 FOR LOCATION OF SECTION)



IDEALIZED GEOLOGIC AND HYDROLOGIC CROSS SECTION

(SEE Plate 1 FOR LOCATION OF SECTION)


West Branch, Little Neshannock Creek
Little Neshannock Creek
Lackawannock Creek
X'
ELEVATION IN FEET ABOVE SEA LEVEL
Pcn
Pco
Mh
Ms
1200
1100
1000
900

SECTION, ALONG LINE X-X'